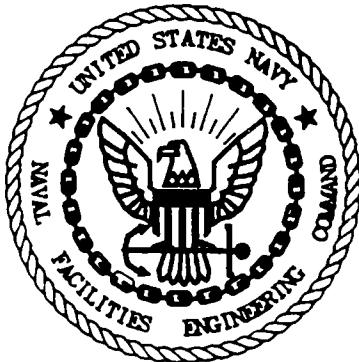


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RESPONSE TO SOUTH CAROLINA DEPARTMENT OF HEALTH AND ENVIRONMENTAL  
CONTROL COMMENTS ON DRAFT RESOURCE CONSERVATION AND RECOVERY ACT  
FACILITY INVESTIGATION ZONE C REPORT CNC CHARLESTON SC  
11/14/1997  
ENSAFE INC.

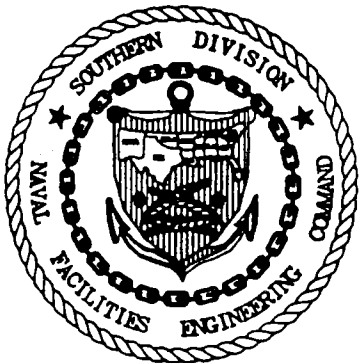


**RESPONSE TO COMMENTS FOR  
DRAFT RCRA FACILITY INVESTIGATION REPORT  
FOR ZONE C  
NAVAL BASE CHARLESTON  
DATED JANUARY 1996**

**CONTRACT N62467-89-D-0318  
CTO-029**

**Prepared for:**

**Comprehensive Long-Term Environmental Action Navy  
(CLEAN)  
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**November 14, 1997  
Revision: 0**

**South Carolina Department of Health and Environmental Control  
Comments on Charleston Naval Base  
Draft Zone C RFI Report  
Dated January 1996**

**Comments by: Johnny Tapia**

**Comment:**

1. A map showing the distribution (depth) of Wando and Ashley formations should be included in the final version of the Zone C RFI Report. As stated in the report, this map should be available once data from deep wells on adjacent zones is obtained. Similarly, on Section 2.2.6 the report states that a vertical hydraulic gradient map will be prepared. The Department hopes to see this map on the final version of this report.

**Response:**

1. A map of the distribution of the Wando and Ashley formations will be included; however, the reviewers need to keep in mind that correlations between the 2 deep wells in Zone C and wells in surrounding zones will be somewhat speculative due to the limited data point control. A vertical hydraulic gradient map will also be included but once again the data will be of limited usefulness because of the low number of data points. (Page 2.17)

**Comment:**

2. Section 2.2.8 "Hydraulic Conductivity" states that the mean value of hydraulic conductivities contained in tables 2.3 and 2.4 are represented on Figure 2.3. The values of hydraulic conductivity represented in Figure 2.3 do not resemble the values contained in tables 2.3 and 2.4. This should be clarified.

**Response:**

2. The data presented on figure 2.3 is incorrect and will be revised to depict the values presented in the referenced tables. (Pages 2.19 and 2.20)

**Comment:**

3. Section 2.2.9, states that "No velocity estimates were made for the deep aquifer since only two deep wells are in Zone C." This statement contradicts the following statement "The groundwater velocity seems to remain relatively constant for both the shallow and deep portions of the aquifer". This comparison cannot be made since groundwater velocity was not calculated for the deep portions of the aquifer and the limited number of deep wells located in this zone. This contradiction should be clarified.

**Response:**

3. The two sentences regarding groundwater which follow table 2.5 are not applicable to the Zone C groundwater velocity discussion and have been deleted. (Page 2.21)

**Comment:**

4. Section 5.2.3. states that from the sampling event, chemical data set were put together for upper soil (surface soil) and the shallow groundwater to compare to background. The same should have been done for the lower interval soil and deep groundwater. How is the Navy planning to address any sort of contamination in the lower soil interval and deep groundwater? Should the number of samples be inadequate to make a thorough investigation of all Zone C media, more samples would be required to collect to complete the investigation.

**Response:**

4. Background values for surface soil, subsurface soil, shallow groundwater, and deep groundwater were agreed upon in May 1997 by the project team. These values are presented in Table 5.1. (Page 5.3) As has been the case with other zones, subsurface soil contamination is evaluated with respect to potential for migration to groundwater. In some instances the project team decides wells are needed and in some cases it is agreed that the concentrations are minimal enough shallow groundwater should not be impacted. Deep groundwater is being compared to background, MCLs, and being evaluated with respect to potential human health risk.

**Comment:**

5. No background values were calculated for lower soil interval or the deep groundwater. If these values are feasible to be calculated it should be done so. There is data from two deep wells at Zone C and not all the second ground interval soil samples were saturated. If there is no possibility of calculating these values, it should be explained; otherwise include these values in the final report.

**Response:**

5. Please refer to response #4 above.

**Comment:**

6. Shallow groundwater background data sets was derived from two sampling points, and on page 5-10 it is stated that reference concentrations were calculated by taking the mean of the two values. However, table 5.6 that depicts the shallow groundwater background



values shows that it was calculated using 2 x mean. This discrepancy should be clarified. The Navy should be reminded that the background values obtained for Zone C are being revised, the same way it was done for Zone B and A.

**Response:**

6. The text has been revised to state background was calculated using twice mean. (Page 5.11)

**Comment:**

7. Table 6.2 includes screening levels for constituents detected in soil and groundwater. Soil screening levels for Aroclor-1254 and Aroclor-1260 were calculated. The calculations of these Soils Screening Levels should be submitted for review. Additionally, some of the footnotes to table 6.2 make reference to Zone I and the acronym NAS has not been defined. These should be corrected.

**Response:**

7. The formula and chemical specific inputs for calculating SSLs are provided either within Table 6.2 or the footnotes with the exception of MCLs (for compounds which have promulgated MCLs) to be used as target soil leachate concentrations. The only part of the calculation possibly not readily apparent are the application of a DAF = 20 and a HQ = 0.1 even though they are pointed out in the footnotes. The acronym NAS will be deleted and replaced with NAVBASE. (Page 6.4)

**Comment:**

8. Section 7.3.9.2 "Comparison of Site-Related Data to Background Concentrations", states that the statistical approach proposed in May 1995 for Zone H, was also approved for Zone C. Recent discussions by the Department questioned the use of this statistical approach to calculate reference concentrations (UTLs). This discussions concluded with the decision of very closely scrutinize grid-based analytical data, before it can be used to calculate UTLs, and even after these values are calculated, they still need to be approved on a zone-by-zone basis. This section should be modified to reflect the current approach taken, to determine "background reference concentrations" (UTLs).

**Response:**

8. The reference to the May 1995 memo has been deleted and a reference to the Zone C specific approach described in Section 5 inserted. (Page 7.12)

**Comment:**

9. The formula for calculating the UCL, in Section 7.3.6.4, a portion is depicted in one page and the rest in another. This minor problem should be corrected.

**Response:**

9. The editorial error will be corrected. (Page 7.17)

**Comment:**

10. Section 7.4 "Site-Specific Human Health Risk Assessments", describes the organization of the RFI risk assessment for each AOC or SWMU. At the end of this section on page 7-50, AOC 522 "Former Grease and Wash Building" and AOC 700 "Golf Course Maintenance Shop" are described as recently identified and added to the Work plan. The status of the investigations at these two sites has changed from the time the Zone C RFI Report was submitted. The information related to AOC 522 and AOC 700 should be included (where applicable) and the results of the investigations submitted for review.

**Response:**

10. Site specific information related to the investigation of AOCs 522 and 700 has been included as Sections 10.8 and 10.9 of the revised report.

**Comment:**

11. Need clarification on the section of ECPC's in section 8.4 "Contaminant Fate and Transport". According to the text, "inorganic parameters in site surface soil exceeding twice the maximum concentration detected in reference sample concentrations, are identified as ECPC". For each sub-zone, the detected inorganic parameters are compared to the Upper Tolerance Limit (UTL) of background. These UTL values used for comparison are not the same as the UTL values determined in Section 5.0, table 5.4. It needs to be clarified how the UTL values for screening of inorganic parameters in the Ecological Risk Assessment were calculated. What samples were used for this determination, etc.? These comments apply through all Section 8.0 of the report.

**Response:**

11. The background values used in the ERA have been corrected. (Pages 5.3, 8.13, and 8.18)

**Comment:**

12. Section 10.1.2 repeats the paragraph of SVOCs in soil. One of them should be eliminated.

**Response:**

- 12. The first paragraph referring to SVOCs will be deleted to eliminate the duplication and so that the organization of the compound specific discussions remains consistent with the remainder of the document. (Page 10.1.8)**

**SWMU 44**

**Comment:**

- 13. Figures 10.1.3 and 10.1.4 show the locations of 21 sediment and surface water samples. The sampling proposed in the Work plan was for 14 samples on each media. These locations cannot be differentiated to reach some kind of conclusion. These tables need to be updated.**

**Response:**

- 13. The figures actually show 13 sediment and 14 surface water sample locations. One sediment sample was not collected as proposed. Section 10.1.10.3, Exposure Assessment provides both a figure (Figure 10.1.5) and text (pages 10-47 and 10-48) which specifically present/discuss the results of soil and sediment sample results.**

**Comment:**

- 14. Section 10.1.5 "Sediment Sampling and Analysis" states that 14 samples were proposed in the Work plan and 13 were collected with the exception of 044M0022. Figure 10.1.3 shows 21 sampling locations, table 10.1.9 shows that the frequency of detection is compared to only 9 samples collected. Appendix D shows the analytical results of only 9 sediment samples. This is confusing and needs clarification.**

**Response:**

- 14. The figure is correct and shows 13 locations which are labeled as 044M0009 through 044M0021. The reason that the frequency of detection is compared to 9 samples is 4 of the samples were only analyzed for total organic carbon and grain size. This will be clarified in Section 10.1.5 of the revised report. (Page 10.1.14)**

**Comment:**

- 15. SWMU 44 soil sampling event detected many inorganics in soil in concentrations above the RBCs. A review of the Draft report and the "hits table" provided to this Department, it can be seen that additional sampling points have been located at SWMU 44, i.e. 044SB025 and 044SB026, which also detected inorganics at levels above the Region III RBCs. Toluene and Methylene Chloride were detected at the only sample location that**

was specifically analyzed for those parameters. It is not known if these chemicals are present throughout the area of SWMU 44 or it was an isolated hit. From all the subsurface samples proposed, only 1 was collected and analyzed. From this analysis, several analytes exceeded soil screening levels for the protection of groundwater. Therefore, it could be misleading to generalize detections or non-detections in the lower soil level throughout the area of SWMU 44. Detections below SSLs may not be protective of groundwater for the area of SWMU 44. Additional information should be provided to reach a reasonable conclusion. Only 1 shallow groundwater well (#6) was analyzed for Appendix 9 parameters. Several detections occurred, and attention needs to be called to well #1, where beryllium, lead and nickel detections exceeded their respective MCLs. Again, only one well (#6) was analyzed for other parameters besides metals. Generalization about findings related to VOCs, SVOCs, and pesticides/PCBs will not be conclusive to render a certain media "clean" for those chemicals. Additional sampling and analyses is required in shallow groundwater at SWMU 44, for parameters other than inorganics. SWMU 44 text should be revised throughout, and if possible include the results of the interim measures performed at the site which will help to determine the current conditions at the site. The final version of this report should include all rounds of sampling for wells at SWMU 44.

**Response:**

- 15. Per the July 1997 project team meeting, 9 soil samples were collected from the existing ground surface to provide confirmation of the effectiveness of the interim measure. The samples will be analyzed for metals and semi-volatile organics. In addition, the existing monitoring wells were sampled for metals and semi-volatile organics. Because of the geographic location of monitoring well NBCC-044-008 with respect to AOC 700, the groundwater sample collected from that were also analyzed for pesticides as part of the resolution to comment #70. (Page 10.1.110)**

**Comment:**

- 16. Section 10.1.9.1 "Soil-to-Groundwater Cross-Media Transport". SWMU 44 was a coal storage area that could have produced a change in the soil pH due to the production of sulfuric acid by rainwater infiltration through the coal. As stated in section 6, Fate and Transport, inorganics have low mobility in normal environments, however in low pH conditions, inorganics can become more mobile. From Appendix D, it was observed that Cation Exchange Capacity, analyzed only at 044SB006 surface soil, shows a comparatively higher value than results for other AOCs or SWMUs in Zone C. pH is one of the factors that affect Cation Exchange Capacity. It is not impossible that soil and possibly groundwater have been affected for the mobility of inorganics due to low pH. The relation of these parameters to soil/groundwater contamination at SWMU 44 should be discussed.**

**Response:**

16. This section will be revised to provide more discussion of pH as the parameters relate to fate and transport at SWMU 44. It should be noted that these conditions no longer exist since the site has been altered by an interim measure. (Page 10.1.24)

**Comment:**

17. Tables 10.1.20, 10.1.21, and 10.1.22 do not have footnotes explaining all the keys used in the tables. Additionally, COPCs for groundwater were identified only based on the first round of sampling. All rounds of sampling should be included in the final report.

**Response:**

17. Footnotes will be added as necessary to explain the various keys used in the tables. The groundwater data presented was the only data available at the time the report was prepared due to the time constraints imposed by the "Facility Submission Schedule" included as Appendix C of the Part B permit and as reflected in the Corrective Action Management Plan required and approved by the Department. A "hits" summary of all four quarters of the data has been included as Appendix H to the report so the reviewer can evaluate trends in the data and the project team can reach conclusions regarding the need for further corrective action. The Navy has proposed that in circumstances where additional data are collected after the report submittal, that the impact that this data has on the recommendations section be evaluated and changed in the conclusions section only. The data will be provided in the form of an appendix in an addendum and referenced in the conclusions narrative. The Navy feels that it is unreasonable to require complete rewrite of the document on the basis of the additional data alone. If this is not acceptable, then the RFI report submittal dates should be after all quarterly groundwater sampling is complete and this submittal date should be reflected in the CAMP.

**Comment:**

18. From the hit tables for Zone C soil sampling, it was observed that Vanadium needs to be added to the list of COPCs in surface soil. It was detected in 044SB025 at a concentration of 68.2 mg/kg, which is higher than its respective RBC value.

**Response:**

18. Tables 10.1.13 and 10.1.20 have been updated to include data from sample locations 044SB025 and 044SB026. Vanadium has not specifically been added to the human health risk assessment since the site is already recommended for CMS and it would not be a primary driver at the concentrations observed.

**Comment:**

19. Figure 10.1.5 needs to include soil borings 044SB025 and 044SB026.

**Response:**

19. Figure 10.1.5 has been revised to include soil borings 25 and 26. (Page 10.1.50)

**Comment:**

20. The Department does not agree with the statement in page 10-89 about lead toxicity. This conclusion is premature, and results of additional rounds of sampling are needed to reach a reasonable conclusion. There is one exceedance on the action level of 15 ug/l, and further evaluation is warranted. The four rounds of sampling will provide additional data before reaching a conclusion.

The nature and extent of Chemicals of Concern (COCs) in the shallow groundwater at SWMU 44, needs to be re-evaluated by considering subsequent rounds of sampling. The fact that arsenic was not detected in background monitoring wells could be due to the use of only two background monitoring wells.

Comparison of maximum detections to other zones background reference concentrations is not acceptable at this time due to the fact that background numbers are in the process of revision for most of the zones at NAVBASE, including Zone C.

The statement made on page 10-90 about the BEHP detections related to common laboratory contaminants should be confirmed and evaluated by subsequent rounds of sampling.

**Response:**

20. Even though SCDHEC may believe the conclusions regarding lead are premature, the recommendation to include the site in the CMS based on the presence of other organics is still valid so from a "big picture" perspective, the outcome for the site is unchanged. The hit of 19.8 ppb was detected in well NBCC-044-001. A review of the subsequent quarters of groundwater data for this well revealed results of 2.4 ppb, 5.7 ppb, and non-detect. Lead was not detected in any other wells above 1.7 ppb in subsequent rounds so the conclusion is still valid. The inclusion of subsequent rounds of sampling was discussed above in response to comment #17. The Navy agrees with SCDHEC's concern related to BEHP which was the basis for the statement on page 10-90 in the report that subsequent data be evaluated to confirm or refute its presence.

**Comment:**

21. It is agreed with the recommendation of considering future groundwater quarterly sampling to confirm the presence of contaminants identified as COPCs in groundwater. This recommendation was directed to 2,3,7,8-TCDD equivalents, but it should be applied to all the COPCs in groundwater, as stated above.

**Response:**

21. The Navy agrees that additional rounds of groundwater sampling will be necessary, most likely as part of the CMS.

**Comment:**

22. Section 10.1.10.6 "Risk Uncertainty" discusses the uncertainty related to the frequency of detection and spatial distribution. The argument is made that since SWMU 44 was almost all fill material, deposited in the past for land reclamation, it would be fair to expect that soils at SWMU 44 will be the same as those of other similar zones (H and I), where the same situation happened in the past. Based on this argument, contaminant detections are compared to calculated background values for the dredge-spoil formed zones. This argument is only partially acceptable. It is true that dredge spoils deposited in the area of SWMU 44 could be the same as those for Zones H and I, but comparing to reference concentrations for those zones seems inadequate, not knowing the origin of the dredge spoils that cover these areas. They could come from different sources that present different levels and types of contaminants. Additionally, according to maps provided to this Department, only about 1/4 of the area of Zone C was covered with dredge spoils, the rest of the area should resemble original soil conditions at Zone C. Reference values calculated for a "all dredge spoil" zone, will normally yield higher values for inorganics, that are being used to calculate reference concentrations. Zone C is expected to yield lower values than for Zones H or I. Therefore, soils and sediments results compared to reference concentrations of Zones H and I is not a good reference for comparison.

**Response:**

22. The SWMU 44 results were screened against Zone C background values, not Zone H and/or I values, to identify COPCs so the reason for the SCDHEC's concern over the point made in the section is not really clear. The Navy agrees that the origin of the dredge spoils for the area of SWMU 44 may or may not be the same as those in Zones H and I. Even so, the probability is likely greater that the spoil material at SWMU 44 is more similar in composition to the Zones H and I spoils than to native soil found in other parts of Zone C. The comment correctly points out that as a whole, Zone C is expected to yield lower values than an all dredge spoil area, hence the reason to point out the uncertainty. Even if no mention were made to Zones H

**and I there would still be uncertainty inherently built into the comparison of the two areas within Zone C. Therefore, the Navy feels this discussion is beneficial to the risk managers.**

**Comment:**

23. On page 10-97, it is not clear if the third paragraph explains the Central Tendency Analysis for SWMU 44. This paragraph concludes by mentioning AOCs and SWMUs combined in SWMU 14. This should be clarified. The first paragraph of this page already talks about Central Tendency in soils and sediments for SWMU 44.

**Response:**

23. **The reference to AOCs and SWMUs combined in SWMU 14 will be deleted and the accuracy of the paragraph verified. (Page 10.1.101)**

**Comment:**

24. Section 10.1.11 "Corrective Measures Considerations at SWMU 44" does not express a clear recommendation by media and contaminant. SWMU 44 should be recommended either for a CMS, NFA, or future evaluation. It is imperative to look at subsequent rounds of groundwater sampling and to consider the present conditions at SWMU 44 before reaching a final decision. Groundwater, especially presents an unacceptable risk to human health in both, residential and worker scenario. For soil and sediments areas 1, 2, and 3 present a risk on the high end of what is acceptable for the residential scenario. Further evaluation and the completion of additional information is required for SWMU 44.

**Response:**

24. **A CMS recommendation has been added. (Page 10.1.116)**

**SWMU 47/AOC 516**

**Comment:**

25. Table 10.2.1 indicates that 17 soil samples were proposed for the lower soil interval, however only 13 samples were collected and the deviations column does not explain the reason. This should be corrected by adding the appropriate explanation for the deviations.

**Response:**

25. **The explanation will be added to the revised table. (Page 10.2.3)**



**Comment:**

26. From table 10.2.3 and 10.2.4 that displays the analytical results for SWMU 47 and AOC 516, for organics and inorganics respectively, it was found that the screening of detections for the lower soil interval, only RBCs were used. When no UTLs can be determined, the detections on the lower soil intervals should be screened against generic soil screening levels, when available. This is the approach currently used at NAVBASE. This table should be modified accordingly.

**Response:**

26. The Navy agrees with this comment and will revise the table accordingly. (Page 10.2.4)

**Comment:**

27. On page 10-11, Section "SVOCs in Soil" states that the three highest BEQs hits were located at 047SB005 (upper), 047SB016 (upper) and 047SB007 (lower). The first two detections were consistently higher than the rest of the samples for all PAHs in the upper and lower soil intervals. However, the Department was unable to verify the analytical results of location 047SB007. This analytical data is not present on Appendix D, nor in the new tables provided to the Department. This data should be provided for review.

**Response:**

27. The data for 047SB007 has been included in the revised report. (Appendix H)

**Comment:**

28. Section 10.2.5.1 "Soil to Groundwater Cross-Media Transport", concludes that concentrations of organics and inorganics detected in soil were above groundwater protective soil screening levels, and that they are considered protective enough of the shallow groundwater aquifer, due to non detections for this constituents in groundwater. These conclusions are premature and although it could be possible, it is reasonable to review additional rounds of groundwater sampling to make a final decision on the impact that soils are producing to groundwater. The final report should include all the results of the four rounds of sampling.

**Response:**

28. This comment will be addressed by the actions described above in response to comment #17.

**Comment:**

29. Page 10.52, "Lead Toxicity" Section, states that even though detections at 047SB00701 were 1,120 mg/kg in surface soil and 1,190 mg/kg in the subsurface soil layer, a "mean" lead concentration of 112 mg/kg was used to calculate health effects for a child. It is not understood how a mean level is used to assess lead health risks while a UCL approach is used for other chemicals of potential concern. The use of this approach should be explained. Since lead concentration at 047SB00701 is above the residential threshold of 400 mg/Kg, the extent of contamination in both, surface and sub-surface soils should be determined.

The Lead Uptake Biokinetic Model used to predict blood lead levels in children considers impacted environmental media such as soil and groundwater. Impacted subsurface at higher levels than the surface could affect the future reuse of the site. The model predicts a child's exposure to lead within a defined area of contamination. Averaging detected concentrations over the total area of SWMU 47 and AOC 516 would not predict the exposure to the area where levels are of concern (above 400 mg/kg). The extent of lead contamination around 047SB00701 first should be defined, before using the prediction model. Furthermore, the lead levels found at 047SB00701 indicate that groundwater may be affected. The analytical data suggests a possible contamination, therefore further evaluation of this area is recommended to evaluate lead's presence in all media. This section should be revised and conclusions rewritten.

**Response:**

29. Per the July 1997 project team meeting discussions, additional sampling for lead around 047SB007 is not required at this time; however, the lead concentrations used in the lead uptake model will be replaced with the values from the much smaller area which includes the borings 516SB001, 515SB002, and 047SB007 since this is the where the battery charging operation was located. Lead in groundwater does present a concern at other portions of the site and will be addressed in the presentation of all 4 quarters of groundwater data. Revisions to the model predictions will not change the original recommendation that the site be included in the CMS. (Page 10.2.54)

**Comment:**

30. Page 10.62, which describes in the text the COCs identified in groundwater at SWMU 47/AOC 516, recommends to wait for subsequent rounds of sampling to evaluate if the detections for lead, antimony, and 3-3'-Dimethylbenzidine were real. There are doubts about entrained sediments in the first round results. It is agreed with this recommendation, however should the detections be confirmed, additional work should be done at this site to determine the extent of groundwater contamination.

**Response:**

30. All 4 quarters of groundwater data were presented to the team as part of the Zone C comment resolution discussion at the July 1997 project team meeting. Levels of the constituents identified above either diminished or were non-detect in subsequent rounds but lead still remains a potential concern. There are currently 14 wells at this site, a number of which are downgradient of the areas of concern. No additional wells were proposed for this site during the meeting since it was apparent from the data the current groundwater data is adequate to characterize the site.

**Comment:**

31. Page 10.64, "Frequency of Detection and Spatial Distribution"  
The writing of this section should be revised and modified according to the background reference concentrations approved on May 12, 1997.

**Response:**

31. The only change necessitated by this comment was the deletion of a reference to arsenic in the statement about UCLs being below background. (Page 10.2.65)

**Comment:**

32. The third paragraph of page 10.64 is confusing on making reference to lead and antimony detections in groundwater, in association with AOC 516. This paragraph should be revised.

**Response:**

32. The intent of the paragraph was to imply that AOC 516, due to its operational history, would be the suspected source of the lead in the area. Contrary to this suspicion, the closest downgradient well to this site, NBCC-047-007 which was erroneously referred to as NBCC-047-001 in the text, did not contain significant levels of lead such as those found in well NBCC-047-001. The paragraph will be revised for clarity. (Page 10.2.65)

**AOC 508/511**

**Comment:**

33. Table 10.3.3 "Organic Compound Analytical Results for Soil" should be corrected for the following:

- There were no exceedances of Benzo(k)fluoranthene in the upper soil sampling interval. Table 10.3.3 states the opposite.
- There is no footnote at the end of the table to explain the meaning of the superscripts used, especially those on the RBCs column.
- The analytical results for Chlordane were not included in the table. It was detected at location 508SB008 at a concentration higher than the RBCs.
- Dieldrin also had a lower soil interval detection on sample 511SB002.
- The section that depicts the results of analyses for TPHs, does not show the same results as found in the analytical data (Appendix D), nor the units are appropriate.

**Response:**

33. Table 10.3.3 will be revised as noted.

**Comment:**

34. For tables 10.3.3 and 10.3.4, the reference concentrations should be updated and exceedances recounted.

**Response:**

34. The tables will be revised to reflect the updated reference concentration and screening results against these concentrations.

**Comment:**

35. Page 10.8, when explaining the SVOCs detections at AOCs 508/511, should clarify the number of samples collected in the lower soil interval. The detections are totalized for the area of these two AOCs, but the shallow water table, in several cases, interfered with the collection of samples in the lower interval. Detections cannot be generalized for an area if samples have not been collected and analyzed for the proposed parameters. In this case, at AOC 508 only one lower soil sample was collected, while at AOC 511 five lower soil samples were collected. The generalization that SVOCs were detected only in upper interval samples could apply to AOC 511, but not to AOC 508. This gives the reader the

wrong picture, which cannot be clarified without doing a thorough review of the analytical data. This comment should be clarified and should apply for all other sites where generalizations of this nature are made.

**Response:**

35. The generalized statement that SVOCs were only detected in upper level samples has been deleted. The available data was screened as suggested by SCDHEC comment #52 to assess the relative significance of the surface concentrations with respect to groundwater screening. (Page 10.3.8)

**Comment:**

36. Page 10.9 makes the statement that TPH concentrations exceeded the 100 mg/kg reference in every sample analyzed. This statement is not accurate and should be revised. Please revise the analytical data.

**Response:**

36. The statement on page 10.3.9 has been revised to accurately reflect the results.

**Comment:**

37. Section 10.3.3.1 "Soil-to-Groundwater Cross-Media Transport".  
This section mentions that contaminant detections in soil and subsurface were compared to SSLs and background reference concentrations. Twelve constituents detected at AOC 508 and AOC 511 exceeded SSLs. Six subsurface samples were proposed to collect at AOC 508, however only 1 sample (508SB004) was collected and analyzed due to the shallow groundwater present at the site. To have an appropriate characterization of AOC 508, it is necessary to have additional samples collected, either soil or groundwater. Groundwater samples will clarify if the groundwater has been impacted by any of the constituents detected in the surface soil.

**Response:**

37. Per the July 1997 project team meeting, a consensus agreement was reached that 2 temporary wells will be installed at these sites. The wells were installed and the results are included in section 10.3.3.

**Comment:**

38. Tables 10.1.13, 10.2.8, and 10.3.5 should be revised to include updated values for UTLs, where applicable. Include also detailed footnotes as done on table 6.2. This comment on UTLs update and tables footnotes applies to all tables similar to the above mentioned ones.

**Response:**

38. The tables will be revised to reflect the current UTLs and appropriate footnotes. (Table 10.3.6, page 10.3.12; Table 10.1.13, page 10.1.22; Table 10.2.8, page 10.1.19)

**Comment:**

39. Mercury needs to be included as a potential contaminant migration from soil to groundwater. It was detected at location 511SB006 lower soil at a concentration of 11.2 mg/kg, which is above the subsurface UTL = 0.30 mg/kg or the SSL = 3.0 mg/kg. Mercury was analyzed in only 3 of the 10 sampling points at AOC 511. Mercury should also be added to the list of COPCs in section 10.3.4.2 and table 10.3.9. In addition, the TPHs exceedances of 100 mg/kg should be revised. Some hits below 100 mg/kg were mistaken by hits above 100 mg/kg due to the units used. These should be revised.

**Response:**

39. Table 10.3.9 is now 10.3.10 and identifies COPCs in surface soil, not subsurface soil. The maximum concentration of mercury was 11.2 mg/kg. The next highest concentration in either surface or subsurface soil was 0.40 mg/kg. Considering the potential source area was less than 1000 ft<sup>2</sup>, the potential for soil to groundwater migration of mercury is very minimal and no threat is anticipated. (Page 10.3.14) The TPH concentration units have been corrected in Appendix H.

**Comment:**

40. The groundwater paragraph of section 10.3.4.2 should be corrected to make reference to AOCs 508 and 511. The same correction needs to be made at tables 10.3.8 and 10.3.9.

**Response:**

40. The corrections were made as noted. (Pages 10.3.14, 10.3.17, and 10.3.18)

**Comment:**

41. On page 10-37 "Lead Toxicity", it is true that the mean of all lead detection falls below the identified protective level of 400 mg/kg, however there are still small areas impacted by

lead levels above 400 mg/kg. This needs to be addressed as a health concern. The Navy should propose further measures to address this contamination.

**Response:**

41. The potential for exposure was calculated separately for both AOC 508 and 511 which are each smaller than the standard ½ acre exposure area. As stated, chronic exposure is not expected to pose a health threat to hypothetical child residents. To state the Navy should take an over conservative approach and address lead at these levels is inconsistent with approaches taken at other NAVBASE sites. (Page 10.3.39)

**Comment:**

42. Section 10.3.4.6 "Risk Uncertainty", should also explain any reason why the risk might be underestimated. For AOC 508 and 511 grouped together, there is uncertainty at AOC 508 about the presence of contaminants in the subsurface unit and how they could be affecting groundwater. Additionally, groundwater was not sampled, therefore, it is not known what conditions the groundwater is in.

**Response:**

42. Monitoring wells were installed to address this concern and the data generated is presented in Section 10.3.3.

**AOC 515/519**

**Comment:**

43. Page 10-10, first paragraph, states that three organophosphorus pesticide compounds (disulfoton, methyl parathion, and parathion) were detected at concentrations below their RBCs in the upper interval soil samples collected for AOC 519. The detection of these compounds was actually at the lower soil level at AOC 515. These statements should be corrected and it should be explained why only the lower level was analyzed for organophosphorus pesticides, not the upper level.

**Response:**

43. The discrepancy in sample locations will be corrected. The organophosphorous pesticides were only analyzed for when duplicate samples were collected which is the reason the analyses appear inconsistent. (Page 10.4.10)

**Comment:**

44. According to the history of AOC 515, it was operated as a paint shop in the 1930s. Potential contaminants identified at this AOC were paints, solvents and petroleum hydrocarbons, among others. Groundwater has not been sampled at AOC 515/519. The focus of the investigations at these two sites was to do a Confirmatory Sampling Investigation, therefore, groundwater should also be sampled and analyzed to verify that no contamination is present at the site. The Navy should propose such strategy.

**Response:**

44. The concept of confirmatory sampling and the manner in which many sites were identified as SWMUs or AOCs simply on the basis of the shop names was discussed at length at the July 1997 project team meeting. The team agreed by consensus that the objectives of the investigation at this site were met and no further investigation is required.

**Comment:**

45. On table 10.4.8 which identifies the COPCs for AOC 515 and AOC 519. Disulfoton is identified as a COPC with a concentration of 1000 ug/kg in soil. This pesticide compound was identified in tables 10.4.3 and 10.4.5 with only one detection of 1.6 mg/kg. The analytical data tables (Appendix D) shows that sample number 519-C-B001-01 MSD had this value for disulfoton. It should be explained why this value of 1000 mg/kg was used to determine Disulfoton as a COPC. Was the same done on the other organophosphorus pesticides from the sample number mentioned above?

**Response:**

45. The list of COPCs will be revised to eliminate those compounds introduced to samples in the laboratory as surrogate recovery spikes and subsequently identified in error as site constituents.

**Comment:**

46. According to the human health risk assessment performed at AOC 515 and 519, no COC were identified because the individual risks fell below  $1 \times 10^{-6}$  and the individual hazard quotient was less than 0.1 for every COPC. It was previously suggested that no defined reuse has been established for these areas, therefore, according to the risk calculations, the contaminants present at the site seem to be protective of the residential exposure scenario. Lead was detected at one sampling point, at AOC 515, at levels marginally above 400 ppm, which is protective of the residential scenario. Assuming that current conditions



at these areas are maintained (paved parking lot), and that the groundwater presents no contamination, AOC 515 and 519 would not require additional investigation.

**Response:**

- 46. SCDHEC's concurrence with the assessment of these sites is noted.**

**AOC 523**

**Comment:**

- 47. Section 10.5.4 "Nature and Extent of Contamination" reports THP (GRO) detection of 12.12 mg/l in monitoring well 523MW002, however, in the section "Other Organics in Groundwater" it is stated that no TPH was detected in groundwater samples from AOC 523. This discrepancy should be clarified.**

**Response:**

- 47. The discrepancy has been clarified. (Page 10.5.12)**

**Comment:**

- 48. According to the criteria for selection of COCs, "a chemical contributing to a cumulative risk level of  $1E^{-6}$  or whose HQ exceeds 0.1" will be identified as a COC. Page 10-36 does not follow this criteria by not identifying Chromium in surface soil as a chemical of concern, contributing with a HQ = 0.15 on the incidental soil ingestion pathway for the potential future child resident. This should be explained. In addition, arsenic has been unnecessarily identified as a COPC for the general risk assessment of groundwater. It was detected at the range of 15.8 to 26.6 mg/l which is higher than the background reference value of 6.07 mg/l but lower than the MCL value. The screening process of these contaminants for groundwater should be redefined throughout the report. Tap water RBCs should be used for screening when no MCLs or background reference concentrations are available.**

**Response:**

- 48. An explanation for the elimination of chromium has been added to the COC identification section. (Page 10.5.38) The screening process of identifying COPCs as described in the Comprehensive RFI Work Plan uses tap water RBCs and background concentrations. The use of MCLs in the screening process has not been clearly defined previously by the Department, except in the cases where background or the tap water RBC has exceeded an MCL. The Navy agrees with the use of MCLs as a value to use in the screening process but rather than redefine the process for identifying COPCs**

**this late in the RFI, the navy suggests that MCLs be considered during the risk management decision making process.**

**Comment:**

49. Section 10.5.7 "CMS Considerations", states that four quarters of groundwater sampling will verify the presence of contamination in the shallow groundwater. The Department agrees with this approach and hopes to see the results of the four rounds of groundwater sampling in the final version of the Zone C RFI Report. Additionally, the Navy has to be reminded that the potential concerns at AOC 523 were gasoline and petroleum products, therefore, due to the detections of TPHs in both soil intervals and groundwater, these parameters should have been analyzed for in the three remaining rounds of groundwater sampling. Although TPH is not considered in the HHRA, it is still of concern, until analytical data shows the contrary.

**Response:**

49. All 4 quarters of groundwater were presented to the team at the July 1997 project team meeting and is presented again in Appendix H. The team agreed by consensus that no further investigation is warranted at this site.

**AOC 510**

**Comment:**

50. Table 10.6.1.3 shows the organic compounds analytical results, for soil in AOC 510. One of the VOCs present on the table is Methylene Chloride. After a review of the analytical data, it was found that Methylene Chloride was detected and qualified UJ or U in all the sampling points. Please explain why this compound was considered a detection. The text stating this should also be modified.

**Response:**

50. The error was made because the text was written prior to completion of data validation. The "UJ" values reflect detections that were eliminated due to contamination found in blanks associated with the samples. This section will be revised. (Page 10.6.1.8)

**AOC 512**

**Comment:**

51. Section 10.6.2.3.1 "Soil-to-Groundwater Cross-Media Transport", evaluates the potential for contamination of groundwater due to the presence of contaminants in the soil, specifically subsurface soil. The cross-media transport is usually evaluated by comparing

subsurface soil detections to the greater of SSLs or background reference concentrations. However, because of the shallow water table, subsurface soil samples were analyzed only at one location (512SB002). This section concludes the detection in the subsurface soil are below SSLs or background, therefore the shallow aquifer is protected. This conclusion is premature and based only on the analysis of one sample from six proposed. This conclusion should be revised and an explanation added to this section dealing with the sampling collection/analysis stated above. This should be added to all AOCs/SWMUs investigated in this zone, especially where groundwater was not analyzed to confirm or refute the conclusion that the shallow aquifer is protected.

**Response:**

- 51. As evidenced in table 10.6.2.5, surface soil results were compare to SSLs where the shallow groundwater table prevented the collection of subsurface samples. SCDHEC agreed with this approach in comment #52. Even so, at the July 1997 project team meeting, a consensus agreement was reached to install 2 temporary wells at this site. The results are presented in Section 10.6.2.3.**

**Comment:**

- 52. AOC 512 was proposed to be sampled in surface soil and subsurface soil. Due to the shallow groundwater (less than 5 ft), only one of six samples were collected and analyzed. Since the lower soil interval was not adequately addressed, it is asked from the Navy that the screening of contaminants be done following the suggested approach:**

- Screen surface soil detections against RBCs/UTLs (whichever is higher) identify COPCs for surface soil.
- In cases where subsurface soil was not adequately sampled due to shallow groundwater, screen surface soil detections against SSLs for protection of groundwater. This way will ensure that we don't live out any contaminant that potentially could affect groundwater and overcome the sampling problem.
- Another approach could be to take some groundwater samples to ensure that nothing has reached the groundwater.

**Response:**

- 52. As stated in response to comment #51, the Navy has done both. None of the pesticide compounds identified as a potential concern were detected in groundwater.**

**Comment:**

53. The Risk Uncertainties section should also discuss the inability of collecting soil samples below one foot, and how this could affect risk calculations, specially if we don't have groundwater samples to verify that contaminants are not present in groundwater.

**Response:**

53. This comment is no longer applicable since groundwater samples were collected.

**Comment:**

54. Section 10.6.2.5 makes corrective measures recommendations according to the risk calculated at AOC 512. It should be added that Beryllium was also a COC for surface soil. Uncertainty related with presence of contaminants in the lower soil level needs to be evaluated as suggested in previous comments. The approach may identify new contaminants of concern that would need to be included in the risk assessment calculations, specially if they are affecting groundwater.

**Response:**

54. Beryllium has been addressed in Section 10.6.2.7 and as stated in response to comment #52.

**AOC 513**

**Comment:**

55. The Department agrees with the recommendation of No Further Action at AOC 513, the Former Morgue, due to lack of contaminant of potential concern identified at this site. No CMS is necessary at this site and can be reused as planned.

**Response:**

56. SCDHEC's concurrence with the assessment of this site is noted.

**AOC 517**

**Comment:**

57. No releases were identified at any media, therefore no CMS would be required based on the available information. The Navy however, should address the lead present inside the building (walls, floor), which according to the planned reuse, could be a health concern issue. This matter is outside the scope of the RCRA corrective action requirements.

**Response:**

- 56. SCDHEC's recommendation and concurrence with the assessment of this site is noted.**

**AOC 518**

**Comments:**

- 57.** Page 10-9, section "Pesticides and PCBs in Soil" states that all pesticides detected at AOC 518 were below their respective RBCs. This statement is mistaken. Chlordane was detected at 518SB001 at a concentration of 7,400 mg/kg which is well above its RBC of 410 mg/kg for soil ingestion. Additionally, extra soil samples were taken to determine the extent of Chlordane contamination around 518SB001. This statement should be corrected.

**Response:**

- 57.** The text has been revised to correct the discrepancy. (Page 10.6.5.9)

**Comment:**

- 58.** Chromium was detected at 518SB010-01 at a concentration of 39.1 mg/kg, which exceeds the residential RBC of 39 mg/kg. Chromium should have been included in the list of COPCs because it also exceeds the background reference concentration of 26.4 mg/kg. This should be corrected.

**Response:**

- 58.** Chromium was excluded as a COPC because it was not detected on site in the hexavalent state. Therefore, the appropriate screening concentration is 7,800 mg/kg. (Page 10.6.5.18)

**Comment:**

- 59.** Table 10.6.5.5 should be corrected to include the appropriate value for Chlordane highest detection in subsurface soil of 1,800 ug/kg. According to the sampling strategy at AOC 518, Chlordane was detected at 518SB001 upper and lower soil intervals. Two more samples were taken to determine the extent of contamination. These two samples, according to Figure 10.6.5.1 were located about 50 feet away from the high detection. This sampling is not considered appropriate to delineate Chlordane contamination. They are too far apart from the high detection. Pesticides have been found at the base on small areas. This sampling should be revised or otherwise explained the rational used to locate the extra sampling locations.

**Response:**

59. The sample locations were discussed at the July 1997 project team meeting where it was agreed that while the spacing may be such that a precise, small area cannot be defined, the sample locations do serve as a boundary for the site to demonstrate a large scale problem does not exist. Consensus was reached that no further investigation is required. The site is recommended for CMS and possibly an interim measure so the overall outcome is not affected.

**Comment:**

60. COCs identified at AOC 518 were Chlordane due to its individual risk greater than  $1.0E-6$  and  $HQ=0.6$  greater than 0.1. Aluminum and copper should have also been identified as COCs based on their HQ greater than 0.1 for the potential future resident child. This section should be corrected.

**Response:**

60. Aluminum and copper have been considered in the cumulative HI for the site which is only 0.6. Since the  $HI < 1$  it was determined that chronic exposures would not result in unacceptable health risks. As a result, COC identification was limited to primary contributors to cumulative risk/hazard. (Page 10.6.5.53)

**Comment:**

61. The recommendation for corrective measures at AOC 518 should be revised in accordance with the answers to be provided for comments on the Draft RFI report. To address the comments, it may be necessary to see what is concluded after the changes. Further assessment may be needed at AOC 518.

**Response:**

61. The CMS recommendations for Zone C have been revised per the October 1997 project team meeting. (Section 11.0)

**AOC 520**

**Comment:**

62. Table 10.6.6.3 should be modified for lower soil detections of beta-BHC pesticide. There were no detections for beta-BHC in the lower soil interval at AOC 520. Methylene Chloride was also detected at the concentration of 37 mg/kg instead of 3.6 mg/kg. These should be corrected accordingly, including the text on page 10-7.

**Response:**

- 62. The table has been modified to reflect methylene chloride was detected at 37 µg/kg. (Page 10.6.6.3)**

**Comment:**

- 63. The Corrective Measures recommendations in Section 10.6.6.4.9 was for no further action (NFA). Methylene Chloride and Cobalt were detected at levels above their respective soil screening levels for protection of groundwater. However, the detections were limited to one sampling point 520SB002 which could produce very limited impact to groundwater. Chlordane, the most often present pesticide in soil, presents a risk below 1E-6 which is protective of the residential scenario. Based on the available information, the Department concurs with the recommendation of NFA for AOC 520.**

**Response:**

- 63. SCDHEC's concurrence with the assessment of this site is noted.**

**GRID SAMPLING**

**Comment:**

- 64. Table 10.7.3 "Organic Compounds Analytical Result for Soils" does not list PCBs detections. These should be included in the list, especially since they were detected above acceptable concentrations (RBCs). This table should also be corrected for the pesticide 4,4-DDE that presented one exceedance, 1,900 ug/kg, above its RBC.**

**Response:**

- 64. The table has been corrected as noted. (Page 10.7.6 and 10.7.7)**

**Comment:**

- 65. According to page 10-11, section "Pesticide/PCB Compounds in Soil", all pesticides detected in the lower interval were at concentrations below their respective RBCs. This statement is incorrect. Chlordane was detected in the lower interval of sample GDCSB039 at 2800 mg/kg, which is above the RBC=490 ug/kg. In addition, 4-4-DDE was also detected at levels higher than its RBC in the upper interval, at locations GDCSB001, GDCSB006, GDCSB008, and GDCSB009. Three of them were above the RBC for Aroclor-1260 in the upper interval, and one of them much higher than the RBC in the lower soil interval. These should be corrected accordingly.**

**Response:**

**65. The text has been revised as noted in the revised report. (Page 10.7.12)**

**Comment:**

**66. From the review of grid-based groundwater data, Methylene Chloride was detected in one of two deep groundwater samples at levels of 12 ug/l, which is above its MCL=5 ug/l. It was concluded, based on literature, that the presence of Methylene Chloride is due to laboratory contamination. It should be demonstrated to the Department's satisfaction that this was the case. Otherwise, this detection could warrant further evaluation.**

**Response:**

**66. As noted previously, a summary of all quarters of groundwater data is presented in the final report. A review of the data has revealed that methylene chloride was not detected in any of the deep grid wells during any of the remaining quarters.**

**Comment:**

**67. Table 10.7.7 should be corrected according to the new approved reference concentrations for Zone C. The text should also be modified, if the change of reference concentrations warrants so.**

**Response:**

**67. Please refer to response to comment #4 above.**

**Comment:**

**68. The following grid-based locations, have signs of contamination in soil and possible effects to groundwater. These areas should be discussed further:**

**GDCSB001: High detections of PCBs and pesticides in soil. Four extra samples were taken to define the extent of contamination, if any (GDCSB045-GDCSB048). Pesticides were detected at lower concentrations which could have defined the area of contamination. This area could not be verified due to the impossibility of locating in the figures, locations GDCSB001, GDCSB045-GDCSB048. This draft report does not provide a conclusion about the effort put on this site. This should be addressed in the final report.**

**GDCSB008: PCBs and TPHs were both detected in upper and lower soil intervals. The lower interval detections could have very well impacted groundwater, due to the its**



shallow nature. Again, this possibility should be discussed and a conclusion reached in the final report.

**GDCSB039:** This soil sample was taken as part of the effort to determine petroleum contamination around building 400. This sample found Chlordane, Dieldrin, and alpha-BHC in the lower soil interval, all above soil screening levels (SSLs). In addition, Chlordane was detected at levels greater than its RBCs in the upper soil level. There is the possibility of impact to groundwater and it should be discussed and a conclusion reached in the final report.

**Response:**

**68. GDCSB001-** The figure and text will be revised. **GDCSB008 -** The text will be revised to include a discussion of the potential for groundwater impacts. **GDCSB039 -** The text will be revised as noted and will include a review of data from wells in SWMU 25 which are immediately downgradient of the site. (Pages 10.7.13 and 10.7.14)

**Comment:**

**69. Section 10.8 AOC 522 "The former grease and wash building".** This site was designated for a CSI and only soil samples were proposed for this site. According to preliminary investigation results, Methylene Chloride has been detected in four of five samples at upper and lower soil intervals, with the concentrations at lower interval above soil screening levels, it is asked from the Navy to collect several groundwater samples to verify that it has not been impacted. These groundwater samples should be analyzed for volatile compounds (VOCs) and metals.

**Response:**

**69. At the July 1997 project team meeting,** data from the downgradient AOC 523 wells was reviewed and a consensus agreement was reached that no further investigation is required; however, at the October 1997 meeting the team reversed it's decision and agreed to collect two groundwater samples using DPT. This is the reason for the additional sampling recommendation in Section 11.0.

**Comment:**

**70. Section 10.9 AOC 700 "Golf Course Maintenance Building"** was designated for an RFI. For this purpose, only soil samples were proposed to collect. The preliminary results of the samples has the indication that VOCs were present at low concentrations. Also, dieldrin detection at 700SB005 was at levels higher than SSLs. Metals like Arsenic, were also detected at concentrations above SSLs and RBCs/UTLs. Chromium was detected at

levels above RBCs/UTLs and SSLs/UTLs at four locations. Nickel detections in the lower soil interval exceeded SSLs/UTLs. These detections warrant the collection of groundwater samples and analyze for pesticides, VOCs, and metals.

**Response:**

- 70. Per the July 1997 project team meeting, well NBCC-044-008, which is about 50 feet downgradient of the site was sampled for pesticides, SVOCs, and metals. The results are discussed in Section 10.9.3.**

**Comment:**

- 71. Corrective Measures requirements were discussed for each area investigation at Zone C. Table 11.1 "Zone C Site Conclusions" should be modified to reflect the considerations and comments produced from the review of the draft Zone C RFI report. Some of the conclusion would change after review and response to comments. This table should be modified accordingly. Section 11.0 may change also, depending on the re-evaluation of risk and selection of COPCs according to the new reference concentrations, therefore sections 11-1 to 11-8 were not reviewed due to the fact that they are subject to change due to previous comments.**

**Response:**

- 71. The Zone C site conclusions and preliminary recommendations have been revised per the October 1997 project team meeting. (Section 11.0)**

**Comment:**

- 72. The ecological risk summary in section 11.9, indicates that only subzone C-1 was evaluated for contaminants present in different media that could affect ecological receptors. According to this, subzone C-1 does not present a risk to terrestrial wildlife. There is a potential risk for vegetation due to copper and arsenic. Sediments in subzone C-1 has potential of risk for aquatic receptors because of the presence of As, Cu, Pb, Hg, Ni. The water quality at C-1 does not pose a risk. Subzones C-2 and C-3 were evaluated only for the presence of contaminants in soil. Data gaps still need to be filled. There is a potential risk to birds at subzone C-2 due to DDT. Terrestrial wildlife is not at risk at subzones C-2 or C-3. Vegetation is at risk at C-2 due to the presence of copper, lead, manganese and zinc. Based on this summary, subzone C-1 needs further evaluation and subzones C-2 and C-3 need to fill data gaps and possible further evaluation.**

**Response:**

- 72. The Navy agrees with this comment. This section is already being revised to address the issues raised at the meeting in Atlanta, October 1996 at which many of the ecological issues were resolved.**

**ENVIRONMENTAL PROTECTION AGENCY  
COMMENTS ON THE DRAFT ZONE C  
RCRA FACILITY INVESTIGATION REPORT  
Dated January 1996**

**GENERAL**

**Comment:**

1. Comments on human health risk assessment are limited to Zone C specific concerns. Comments on the general procedure for human health risk assessment which were made in the Zone H RFI Report apply here also without restatement.

**Response:**

1. The human health risk assessments comments made for the Zone H RFI Report will be reviewed and applicable changes made to the Zone C RFI Report.

**Comment:**

2. The format used for Sections 5.0 (Nature and Extent of Contamination) and 10.0 (Site-Specific Evaluations) makes the text difficult to follow. Except for a discussion of data related to background comparisons, the actual nature and extent of contamination are not presented until Section 10.0, after the presentation of the risk assessments. It would be better to incorporate Section 10.0 in Section 5.0 for the Final Zone C RFI Report.

**Response:**

2. The format used is intended to consolidate all the site specific information in one section to facilitate the review process. This format has been accepted by the project team and will continue to be used unless the team decides otherwise.

**Comment:**

3. Based upon the data presented on Page 8-11, Table 8.2a, only one surface soil samples was used to evaluate risk to terrestrial receptors in Sub-zone C-1. Use of only one sample greatly increases the uncertainty associated with the risk characterization, since it is not known how representative it is of site conditions. Also, since the sample contained elevated levels of inorganics and was located at the northern part of SWMU 44, the northern extent of the surface soil contamination has not been defined. It is recommended that at least two additional surface soil samples be collected in Sub-zone C-1 and analyzed for use in the terrestrial ecological risk assessment for this sub-zone.

**Response:**

3. Two additional surface soil samples were collected in the northern part of Subzone C-1 to define the northern extent of SWMU 44 contamination. The analytical results from

these samples have been incorporated into Section 8.0 of the revised Zone C RFI Report. The locations are identified as 044SB025 and 044SB026 on Figure 8.2.

**Comment:**

4. The main purpose of sampling surface water and sediment at SWMU 44 (located in the vicinity of sub-zone C-1) was to check for possible contaminant migration from the SWMU 44 coal piles toward Noisette Creek. Pages 8-12 and 8-13, Tables 8.2b and 8.2c, apparently present sediment and surface water data for the drainage ditches/runoff pathways at SWMU 44. If these ditches contain aquatic habitats, risk can be determined for ecological receptors in the ditches themselves. However, the ditches are important as migration pathways to Noisette Creek and its aquatic receptors. This must be addressed in the risk assessment.

**Response:**

4. At the time of the sampling, aquatic habitats were not observed in the drainage ditches. The ecological risk posed by SWMU 44 to downgradient aquatic receptors has been preliminarily assessed through the evaluation of surface water and sediment samples collected in both the onsite drainage ditches themselves and at the outfall to Noisette Creek. A complete assessment of Noisette Creek will be conducted during the Zone J RFI and summarized in that RFI Report.

**Comment:**

5. Analytical data from the surface water and sediment samples collected in Noisette Creek in conjunctions with SWMU 44 (Pages 10-16 and 10-17, Figures 10.1.3 and 10.1.4) should be qualitatively compared to analytical data from the SWMU 44 surface soil and the ditch surface water and sediment to evaluate contaminant migration from SWMU 44 into Noisette Creek. The Noisette Creek data must also be compared to the surface water and sediment screening values to determine the potential for ecological risk. An further evaluation of risk through site-specific ecological sampling or testing would be deferred to the Zone J investigation.

**Response:**

5. See response to comment 4. The SWMU 44 surface water and sediment samples in Noisette Creek have been compared to upgradient SWMU 44 ditch samples. For a preliminary ecological risk assessment, the concentrations detected in the Zone C Noisette Creek samples will be compared to applicable screening values.

**Comment:**

6. Based upon Page 8-3, Figure 8.2, and the individual figures for the SWMUs and AOCs in Section 10, there are no SWMUs or AOCs at Sub-zone C-3 (detention ponds). In addition, it is not clear whether there are any SWMUs or AOCs with contaminant migration pathways to the Sub-zone C-3 ponds. Data used to evaluate risk to Sub-zone C-3 receptors apparently consists of grid-based surface soil data (Figure 8.2). According to Page 5-4, Section 5.2.1, the purpose of the grid-based soil samples was to determine background levels of inorganics, rather than soil contaminant concentrations related to SWMUs or AOCs. Therefore, the determination of terrestrial risk based upon the grid-based soil data is not appropriate and should be deleted from the risk assessment. If there are contaminant migration pathways from SWMUs and AOCs to the C-3 detention ponds, then surface water and sediment samples should be collected from the ponds, and the analytical data should be used to determine risk to receptors inhabiting or using the ponds.

**Response:**

6. During the basewide ecological survey which was conducted prior to any AOC or SWMU-specific investigations in Zone C, the assessment of Subzone C-3 (formerly AEC III-2) was properly included in the Zone C RFI Work Plan because of the sensitive habitat types found therein and the uncertainty of any NAVBASE impacts on them. After subsequent Zone C assessments of the surrounding area, however, no significant SWMU or AOC-related contaminant migration pathways to the detention ponds were observed. Thus, it is agreed that with the absence of such pathways, an ecological risk assessment of Subzone C-3 is unnecessary. Therefore, the ERA of Subzone C-3 has been deleted from the revised Zone C RFI Report.

Furthermore, the only NAVBASE RFI site identified in the vicinity of the detention ponds is a portion of AOC 504, the base railyards. These railyards are being assessed during the Zone L RFI. If any contaminant migration pathways to Subzone C-3 are identified during the Zone L investigation of AOC 504, the necessary ecological risk assessment will be performed.

**SPECIFIC**

**Comment:**

1. Page vi, Table of Contents, List of Tables, Tables 2.7 and 8.7 - The footnotes are missing.

**Response:**

1. The footnotes are included in the tables themselves. The footnote annotations have been removed from the Table of Contents.

**Comment:**

2. Page xiii, Abbreviations, Acronyms, and Symbols for NAVBASE Zone C- The acronym and definition are provided for Wisconsin Occupational Health Laboratory. EPA does not understand the significance of these in the Naval Base Charleston Zone C RFI Report in South Carolina.

**Response:**

2. The acronym list provided is a generic, all inclusive list of acronyms used to date in the NAVBASE RFI documents.

**Comment:**

3. Pages 1-2 and 1-3, Figures 1.1 and Figure 1.2 - These figures are identical. Replace one of them with a figure showing the locations of all of the Solid Waste Management Units (SWMUs) and Areas of Concern (AOCs) within Zone C.

**Response:**

3. The figures have been replaced as follows: **Figure 1.1 Vicinity Map; Figure 1.2 Locations of Land Holdings and Occupants; Figure 1.3 Investigative Zone Boundaries; Figure 1.4 Zone C Location Map.**

**Comment:**

4. Page 5-2, Sections 5.0 and 5.1 - In the text, clarify that the comparison of detected organic and inorganic chemical concentrations to the USEPA Region 3 RBC Table pertains only to the protection of human health and does not address protection of ecological receptors.

**Response:**

4. The text has been revised as noted in the comment. (Page 5.1)

**Comment:**

5. Page 5-9, Section 5.2.5 - The statement is made that: This is the approach favored by the Ohio Environmental Protection Agency and the Texas Natural Resource Conservation Commission to determine whether onsite contamination is greater than background.

Since Naval Base Charleston is located in South Carolina, the appropriate issue is not "the approach favored by the Ohio EPA and the Texas NRCC to determine whether onsite contamination is greater than background" but rather the approach favored by South Carolina.

**Response:**

5. Section 5.2.1 provides a description of the background method accepted by the project team for use in Zone C.

**Comment:**

6. Page 5-13, Section 5.2.9 - Reference to EPA documents is appropriate anytime; reference to other State's documents is not.

**Response:**

6. The reference to other state documents has been deleted. (Page 5.14)

**Comment:**

7. Page 6-1, Section 6.0 - The theory and application of Fate and Transport are discussed. The discussion leads up to, but stops short of, making a conclusion. The questions that need to be answered here are:
- a. What is the contamination, where is it coming from, where is it going, and how is it getting there? And,
  - b. What is the horizontal and vertical extent of contamination?

**Response:**

7. The answers to these questions are provided in the Section 10 site specific discussions. Similar to comment 2 above, the intent was only to provide the theory in the early sections and provide the application in Section 10.

**Comment:**

8. Page 7-18, Section 7.3.6.5 - the statement is made that: Because Zone C is part of BRAC III, future site use cannot be assumed with certainty. The intent of this statement is unclear and open for a wide variety of interpretations. It should be clarified and specific.

**Response:**

8. Text has been added to state what is known about the intended future use of the Zone C area. The intent of the sentence was to inform the reader that, while proposed reuse plans exist, the plans are subject to change. To accommodate the potential for change, the risk assessment evaluates both a conservative future child resident



**scenario and a less conservative future adult worker scenario to provide the risk managers a wide range of remedial goals. (Page 7.19)**

**Comment:**

9. Page 8-1, Section 8.0 - The statement is made that: This methodology is described in detail in the Final Zone J RFI Work Plan (submitted November 22, 1995). This raises two points:
- a. A Comprehensive RFI Work Plan has been developed and approved for work to be done at two or more zones. Each Zone Work Plan is intended to be specific for that zone. Thus, any reference to a more detailed description of this methodology should be to either the Comprehensive RFI Work Plan or a Section in the Zone C RFI Work Plan.
  - b. The Zone J RFI Work Plan is still draft and should be referred to accordingly.

**Response:**

9. The text has been revised to read: "This survey methodology, which is used in conjunction with the Zone C RFI Report, is also described in the Zone J RFI Work Plan." (Page 8.1)

**Comment:**

10. Page 8-3, Figure 8.2 - a. In the legend, add short descriptive phrases for the three ecological sub-zones (e.g., C1 - scrub-shrub area; C2 - low-lying grassy area with trees; C3 - detention ponds). b. In order to determine the possible relationship between SWMUs/AOCs and the ecological sub-zones, show the locations of the Zone C SWMUs and AOCs in this figure.

**Response:**

10. Figure 8.2 has been revised as requested.

**Comment:**

11. Page 8-4, Section 8.1 - In this section, or Page 8-8, Section 8.3, include a list of SWMUs and AOCs potentially affecting each of the three sub-zones in Zone C.

**Response:**

11. A table of SWMUs and AOCs associated with each subzone has been added. (Page 8.4)

**Comment:**

12. Page 8-5, Section 8.1 - For Sub-zone C-2, indicate whether the runoff ditches are possible contaminant migration pathways from AOC 512, and whether they flow into a tributary or end in the low-lying area at C-2.

**Response:**

12. The text has been revised to include the statement that the Subzone C-2 ditches are potential contaminant migration pathways from AOC 512 and that they ultimately drain into Noisette Creek. (Page 8.5)

**Comment:**

13. Page 8-8, Section 8.2 - Sub-zone C-1 and SWMU 44 are located adjacent to Noisette Creek. Therefore, add a comparison (table and text) of SWMU 44 ground water chemical concentrations to the Region 4 surface water screening values (See Page 10-24, Section 10.1.9.2).

**Response:**

13. Because Section 10.1.9.2 acknowledges the potential significance of groundwater to surface water contaminant transfer, either table 10.1.13 will be modified or a similar table created which compares groundwater data to ambient water quality criteria.

**Comment:**

14. Page 8-10, Section 8.3 - Clarify whether the inorganic analytical data for surface soils were compared to two times the background inorganic concentrations or to the "Upper Tolerance Limit of Background" (e.g., Page 8-18, Table 8.4b).

**Response:**

14. Inorganic analytical data were compared to Upper Tolerance Limits of background. The text has been corrected. (Page 8.9)

**Comment:**

15. Pages 8-11 through 8-18, Tables 8.2a through 8.4b - Include the measurement units for the columns headed "Upper Tolerance Limit of Background" and Effects Level."

**Response:**

15. The appropriate units have been added in the revised RFI Report. (Page 8.13)

**Comment:**

16. Page 8-13, Table 8.2c - a. Since the surface water quality criteria and screening values for some metals are hardness-dependent, add a footnote indicating what hardness value was used. (That is, were the criteria adjusted for site-specific hardness?). b. Since total chromium was measured in surface water, and hexavalent chromium is more soluble than trivalent chromium, include the chronic effects levels for both trivalent (103  $\mu\text{g/l}$ ) and hexavalent (50  $\mu\text{g/l}$ ) chromium. c. Include the freshwater screening value for iron (i.e., 1,000  $\mu\text{g/l}$ ).

**Response:**

16. A footnote has been added stating that the reported concentrations of hardness-dependent compounds have not been adjusted for site-specific hardness. (Page 8.15)

To be consistent with the effect levels presented in the table, the 1995 USEPA Chronic Freshwater Surface Water Screening Values for chromium III and VI (117.32  $\mu\text{g/l}$  and 11 $\mu\text{g/l}$ , respectively) have been added.

The freshwater screening value for iron has been added.

**Comment:**

17. Pages 8-19 to 8-22, Section 8.4 - Although this section on "Stressor Characteristics" is under the heading "Contaminant Fate and Transport", it includes some information on ecological effects. In future RFI reports for other zones, it would be better to include all of the effects information in the same section.

**Response:**

17. The ERA format has been revised so section headings are more consistent with the text provided below them.

**Comment:**

18. Page 8-23, Section 8.5.1 - Revised the last line to read "qualitatively measured by comparing literature data on toxic effects to actual soil concentrations."

**Response:**

18. The text has been revised as requested. (Page 8.20)

**Comment:**

19. Page 8-24, Section 8.5.4 - Since Sub-zone C-3 consists of two detention ponds, check the first sentence to see if it should refer to Sub-zone C-1 instead of C-3.

**Response:**

19. The referenced text has been corrected. (Page 8.23)

**Comment:**

20. Page 8-30, Section 8.7 - The point made in Paragraph 1 about the use of different concentration units is understandable. However, since the analytical data are presented in units of  $\mu\text{g/kg}$  or  $\text{mg/kg}$  (for example), rather than in ppb or ppm, it is preferred that the former units be used in future discussions.

**Response:**

20. The units have been converted to  $\mu\text{g/kg}$  and  $\text{mg/kg}$  rather than ppb and ppm. The statement regarding different concentration units has been deleted since a "standardized" convention is now being used. (Page 8.30)

**Comment:**

21. Pages 8-30 to 8-37, Section 8.7 and 8.7.1, and Pages 8-54 to 8-56, Section 8.7.3 - Most of the information in these sections pertains to ecological effects and, therefore, would be more appropriate in Section 8.6 (Ecological Effects Assessment), beginning on Page 8-24. Risk characterization actually begins on Page 8-37 for terrestrial infaunal invertebrates and Page 8-56 for terrestrial vegetation.

**Response:**

21. This format discrepancy is noted and revisions have been made to Section 8 as requested.

**Comment:**

22. Page 8-37, Section 8.7.1 - a. General Comment - Include a statement indicating how risk to terrestrial infaunal invertebrates was characterized (e.g., for Sub-zone C-1, comparison of maximum surface soil concentrations for the Ecological Chemicals of Potential Concern (ECPCs) in Table 8.2a to ecological effects concentrations in Table 8.6). b. For Subzone C-1, the statement is made that, aside from copper, "Other inorganic concentrations were below effects levels reported in the literature." This statement is not fully supported. For example, Table 8.2a lists arsenic as an ECPC, but Table 8.6 does not include the ecological effects data for arsenic. Therefore, it is not clear whether arsenic presents a risk to terrestrial infaunal invertebrates. If ecological effects data are not available for particular ECPCs, say so in the text; the lack of effects data is an uncertainty with respect to the risk characterization, as mentioned on Page 8-58, Section 8.8. (This comment also applies to the other subzones discussed in this section.) c. Include the basis for the statement that "No risk to infaunal organisms from organic concentrations found at Subzone C-2 are predicted." d. This section states that "No inorganic data were available for soil within Subzone C-3." Since inorganic data for Subzone C-3 are presented on Page 8-18, Table 8.4b, the statement must be clarified.

**Response:**

22. The text has been revised to explain the comparative method used for terrestrial infaunal invertebrate risk characterization. (Page 8.33)

Further discussion regarding the uncertainties resulting from incalculable risk (i.e., no effects data) has been added to the revised section.

This statement has been revised to read "Risk to infaunal organisms from organic concentrations found at Subzone C-2 cannot be predicted due to lack of effects level information on the detected parameters."

Subzone C-3 has been deleted from the Zone C ERA (See the response to comment 6).

**Comment:**

23. Page 8-42, Table 8.11a - Check the series of U.S. Fish and Wildlife Service Contaminant Hazard Reviews by Ronald Eisler for reference toxicity values (RTVs) for the inorganics for birds (e.g., Eisler, Ronald. 1988. Arsenic Hazards to Fish, Wildlife, and Invertebrates: A Synoptic Review. USFWS Contaminant Hazard Reviews, Report No. 12.). Also, see RTVs for inorganics for the American Robin, Page 8-43, Table 8.11b.

**Response:**

- 23. The TRV values have been updated as requested in the revised RFI Report. (Page 8.41)**

**Comment:**

- 24. Pages 8-38 to 8-53, Section 8.7.2 - Food chain calculations based upon maximum surface soil contaminant concentrations show a potential risk (sublethal effects) for terrestrial wildlife. Therefore, it is recommended that mean contaminant concentrations also be used in determining potential dietary exposure, to give a risk range and to determine whether risk is related to localized vs. widespread areas of high contaminant concentrations.**

**Response:**

- 24. Both the maximum and mean contaminant concentrations will be used to assess localized and widespread risk. (Pages 8.34 - 8.49)**

**Comment:**

- 25. Pages 8-56 to 8-57, Section 8.7.3 - a. Include a statement indicating how risk to terrestrial vegetation was characterized (e.g., for Sub-zone C-2, comparison of the maximum soil chemical concentrations for the ECPCs in Table 8.3 to the ecological effects concentrations in Table 8.14 and in the text.) b. For each sub-zone, indicate why "Effects from organic concentrations could not be assessed." (For example, lack of sampling data or lack of ecological effects data.)**

**Response:**

- 25. The text has been revised to explain the comparative method used to characterize risk to terrestrial vegetation. (Pages 8.49 - 8.52)**

**Text has been added regarding how the absence of ecological effects data and sampling data for certain subzones prohibited the assessment of ecological effects from organic constituents.**

**Comment:**

- 26. Page 8-57, Section 8.7.3 - The text states that the manganese concentration exceeded the effects levels reported in the literature, yet no literature data for manganese are presented on Page 8-55, Table 8.14, or in the text. Include the effects levels.**

**Response:**

- 26. The reference to a manganese effect level was in error and has been deleted from the revised text.**

**Comment:**

- 27. Page 8-57, Section 8.7.4 - a. In paragraph 1, last line, change "surface water quality" to "aquatic receptors." b. For Sub-zone C-1, include a reference to Page 8-13, Table 8.2c. State that iron and cadmium exceeded the water quality criteria (Table 8.2c and comment given above). Also, mention that surface water and sediment samples were not analyzed for organic compounds. c. As mentioned above, if the drainage ditches contain aquatic habitat, risk must be evaluated for aquatic receptors in the ditches. The risk characterization must include an evaluation of the potential for SWMU 44 contaminants (based upon concentrations of chemicals found in ditch surface water and sediment and in ground water) to migrate to Noisette Creek at levels that could pose a risk to aquatic receptors in the creek. Also, include an initial risk evaluation of the Noisette Creek surface water and sediment samples collected near SWMU 44. d. Explain why it would be difficult to determine "specific impacts to receptors" in relation to surface water and sediment chemicals which exceeded their effects levels. EPA Region 4 generally recommends that further evaluation and possibly site-specific biological testing be conducted for media samples with chemical concentrations exceeding the screening values.**

**Response:**

- 27. The text has been revised as requested. (Page 8.53)**

**A reference to the table of inorganic constituents detected in Subzone C-1 surface water has been added. The fact that organic constituents were not analyzed for at Subzone C-1 has also been added along with a list of those inorganic concentrations which exceeded the water quality criteria. (Page 8.52)**

**Based on the conditions observed in the SWMU 44 ditches, it is unlikely that they could support a significant viable aquatic habitat.**

**The Navy agrees that biological testing could be used to answer the question concerning minimal impacts. However, since concentrations only minimally exceed screening values, a risk management decision should be made as to whether more sampling is really needed. The statement in the text has been revised. (Page 8.53)**

**Comment:**

28. Page 8-59, Section 8.9 - a. As written, the ecological risk assessment does not present sufficient information to make a decision concerning the possible need for corrective action at different AOCs or SWMUs. Several data gaps are mentioned in the text and in comments contained herein. These data gaps must be addressed in order to finalize the ecological risk assessment. This again points out the apparent lack of a mechanism for proceeding from Phases I and II to Phase III of the ecological risk assessment prior to submission of a draft RFI Report. (EPA can work with EnSafe to recommend a mechanism appropriate to the Navy and EPA). b. Revise this section, based upon ecological risk comments given above.

**Response:**

28. Following the October 30, 1996 meeting with EPA and SCDHEC in Atlanta, the only data gap identified was the need to collect a couple more samples at SWMU 44. The mechanism to discuss site specific results and need for further action appears to be the project team meetings. The text is being revised per these comments and the October 1996 meeting agreements.

**Comment:**

29. Page 9-1 to 9-3, Sections 9.0 and 9.1, and Page 9-7, Section 9.4 - The wording in these sections implies that only human health concerns will be the basis for determining the need for a Corrective Measures Study. Depending upon the final outcome of the Ecological Risk Assessment, ecological concerns might also need to be addressed through corrective action.

**Response:**

29. The text has been revised to clearly state that ecological concerns will be included and addressed in the Corrective Measures Study. (Page 9.1)

**Comment:**

30. Page 9-9 to 9-11, Sections 9.4.2, 9.4.3, and 9.4.4 - These sections include consideration of "The potential for damage to domestic animals, wildlife, food chains, crops, vegetation, and physical structures caused by exposure to waste constituents." Since domestic animals, crops, and physical structures are not addressed in ecological risk assessments, it would be better to include them in a separate sentence.

**Response:**

30. The text has been revised as requested. (Page 9.9)



**Comment:**

31. Page 9-1, Section 9.0 says in part that: the RFI Report should discuss whether the extent of contamination has been defined, and propose recommended actions for the SWMUs and AOCs, such as collection of additional samples, proceed into a Corrective Measures Study, or No Further Investigation, whichever is appropriate.

EPA agrees with this former SCDHEC comment. Yet, Section 9.0 does not fully satisfy this comment. This section summarizes what is contained in the USEPA guidance documents RCRA Corrective Action Plan (USEPA, 1994) rather than dealing with the site specific CMS issues. Section 9.0 is a very important section which should serve as a focal point for the rest of the Zone C RFI Report. It should summarize which areas are clean and require No Further Investigation, which areas need additional samples (how many, where, what type, etc.), and which areas should proceed into the Corrective Measures Study. Further, it should identify the boundaries of each site ("the extent of contamination"). The extent of contamination is critical to designing a CMS.

**Response:**

31. Like most of the other sections which precede Section 10, Section 9 was primarily intended to discuss general issues. Section 10 and the conclusions/recommendations in Section 11.0 reflect consensus opinion of the project team regarding NFI on CMS decisions. The Navy agrees that if the extent of contamination is not adequately defined, these decisions cannot be made.

**Comment:**

32. Page 9-26, Section 9.8 - A discussion is presented of a system for ranking the corrective measure alternatives. The statement is made that: The ranking system will apply a weighing factor selected by the Navy to determine the importance of each corrective measure criterion. However, the use to be made of that information is not provided. It should be noted that RCRA corrective action includes a public participation process. Specifically, while the Navy can recommend corrective measure alternatives, public input will be actively solicited and weighed heavily in the decision which will be made by the RCRA Permitting Authority (i.e., SCDHEC) as to which actual corrective measure is selected for each site. This emphasizes the importance of getting and keeping the Restoration Advisory Board informed and actively involved in the decision making process throughout the RFI and CMS.

**Response:**

- 32. The concerns expressed in this comment have been addressed by the development of a Comprehensive CMS Work Plan. During the development of that plan, the RAB's input was sought in determining the order of importance of the weighting factors.**

**Comment:**

- 33. Page 10-2, Figure 10.1.1 - Since two sampling locations are labeled 044SB006, one of them needs to be corrected.**

**Response:**

- 33. The discrepancy has been corrected.**

**Comment:**

- 34. Page 10-9, Section 10.1.2 - In the cyanide discussion, the subject document states that 4.3 mg/kg is below the RBC of 160  $\mu$ g/kg. The document seems to contain many errors such as this. It is recommended that this document be thoroughly proofed before resubmission.**

**Response:**

- 34. The Navy agrees. The document will undergo both professional peer review and technical editing.**

**Comment:**

- 35. Page 10-12, Table 10.1.6 - Please check the units. Even if it were possible to accurately analyze a contaminant at such levels, it is not possible to get samples that could be duplicated.**

**Response:**

- 35. The units in the table have been verified.**

**Comment:**

- 36. Page 10-13, Table 10.1.7 - This data should be reviewed and discussed in terms of sample turbidity.**

**Response:**

- 36. Turbidity measurements were reviewed and are generally below 10 NTU. For inorganics and organics that have an affinity for adsorbing to entrained sediment, it is unlikely turbidity has had a significant effect on results.**

**Comment:**

- 37. Page 10-1, Section 10.1, SWMU 44, Coal Storage Area - Apparently, arsenic (from the coal???) has contaminated the soil and groundwater at levels that may present a problem. This requires clear delineation.**

**Response:**

- 37. Arsenic in shallow groundwater has been identified as a potential human health risk driver in Section 10.1.10.5 even though it was present a concentrations below it's MCL.**

**Comment:**

- 38. Page 10-1, Section 10.2, SWMU 47 and AOC 516, Former Burning Dump - The cancer risk from groundwater is driven by a single detection of dimethyl benzidine. This is remarkable in that a benzidine compound was also found in groundwater at Zone H. Lead is present in groundwater at unacceptable levels. Lead is present in soil above the residential screening level of 400 mg/kg; however, the average lead concentration in soil is about 800 mg/kg and below the adult cleanup level of 1,300 mg/kg derived using the Bowers model. Given that the future use is expected to be a parking lot, lead in soil should not present a risk management problem.**

**Response:**

- 38. The dimethyl benzidine was only detected during the first quarter of sampling and it's apparent presence can not be explained. The Navy shares a concern with lead levels in groundwater but is not ready to concede that remedial measures are required until ambient water quality issues are resolved. The exposure area for lead at the sites is being reduced to look at a 120 foot by 120 foot area with the maximum detection at 0445B007 used as the EPC. This should answer SCDHEC concerns regarding worst case.**

**Comment:**

- 39. Page 10-1, Section 10.3, AOC 508, and AOC 511, Former Incinerator and Oil House - Lead was present in surface soil above the residential screening level of 400 mg/kg;**

however, the high hit of lead was 768 mg/kg and should not present an unacceptable risk based on the future land use as a community support area.

**Response:**

**39. The project team has agreed with this observation.**

**Comment:**

**40. Page 10-1, Section 10.4, AOC 515 and AOC 519, Former Incinerator and Boiler House - Disulfoton was indicated in Table 10.4.8 to be a COPC. However, it was detected below its RBC. The concentration given in the table was wrong and should be corrected.**

**Response:**

**40. The value presented was for a matrix spike sample which should not have been presented as a site constituent. Table 10.4.8 has been revised.**

**Comment:**

**41. Page 10-1, Section 10.5, AOC 523, Former Gas Station - Aluminum is a COPC in groundwater; for a residential scenario, it is present only very slightly above its RBC. Given the uncertainty with aluminum toxicity, this might become a risk management decision.**

**Response:**

**41. The Navy agrees with this observation.**

**Comment:**

**42. Page 11-1, Conclusions - The table on this page presents conclusions for the risk assessment to determine which sites should move to CMS. In general, EPA is in agreements with the conclusions in this table and feel, if anything, that these conclusions are overly conservative. For the ubiquitous contaminants lead and PAHs, the land use should be factored into the decision to perform a CMS.**

**Response:**

**42. The conclusions will be reviewed and a consensus agreement on site status reached by the project team prior to resubmittal of the report.**

**Comment:**

43. Page 10-1, Section 10 - These discussions need to conclude with a discussion of the horizontal and vertical extent of contamination which is critical to the design of a Corrective Measures Study (CMS) where a CMS is needed and to the transfer of property where an area is demonstrated to be "environmentally clean". Maps should display these areas. Subsequent to the submission of this draft RFI Report, EPA has reviewed draft maps which have been developed to address this concern. EPA is satisfied that if these maps are developed, this concern would be adequately addressed.

**Response:**

43. The maps referred to are assumed to be the risk based maps presented to the project team. Risk and/or concentration maps have been included in the revised report.

**Comment:**

44. Page 10-1, Section 10.6.1 - The statement is made that: The Final Zone C Work Plan (E/A&H, February 1995) required residue sampling to be collected from a pit on the west of Building NH-21; however, no samples were collected since no sediment, liquid, or other residue was observed in the pit. The purpose for the pit sampling was to determine the results of possible releases of solvents from Building NH-21. This determination still needs to be made. In the future, EPA recommends that before such deviations are made from an approved work plan, Naval Base Charleston consult with SCDHEC and EPA.

**Response:**

44. The purpose of the pit sampling was to determine if any wastes remain which need to be properly characterized for disposal. The objective of assessing whether a release had occurred was met by installing soil borings outside the pit.

**Comment:**

45. Page 10-7, Table 10.6.2.4 - Check the high-end concentration in the chromium concentration range for a possible decimal error (i.e., 21.7 mg/kg rather than 21,700 mg/kg chromium?).

**Response:**

45. The result in question was for soil sample 512SB006-01 and the result was 21.7 ppm. Table 10.6.2.4 has been corrected.

**Comment:**

46. Page 10-14, Section 10.1.5, and Page 10-15, Section 10.1.7 - In the text, tell why sediment sample 044M0013 (Page 10-16, Figure 10.1.3) and surface water sample 044W0013 (Page 10-17, Figure 10.1.4) were not collected at the same location.

**Response:**

46. The text has been revised to note that no water was present when the sediment sample was collected; therefore, an alternate location was sampled. (Page 10.1.14)

**Comment:**

47. Page 10-90, Section 10.1.10.5 - The statement is made that: BEHP is a common lab artifact and detections in this range are often related to exogenous source. This raises three points: a. Good laboratory practice has ways of avoiding, or at least minimizing, lab artifacts. b. Good laboratory practice has ways of identifying when a chemical in a sample is a true sample ingredient and when it is a laboratory artifact. c. Simply identifying that a chemical is sometimes found as a lab artifact does not explain the chemical in the samples collected at Naval Base Charleston. Should such a lab artifact question arise, EPA would expect the laboratory to identify and resolve the issue or the Contractor to collect additional samples for analysis in a different laboratory. Fact rather than conjecture is needed here.

**Response:**

47. The Navy and their contractor have ensured via contractual mechanisms that the subcontract laboratories will follow proper quality assurance protocol. The data validation reports were provided as an appendix to support the statement made.

**Comment:**

48. Page 11-1, Section 11.0 - The discussion focuses on specific sites but does not relate the grid sites to the specific hazardous waste sites. This correlation needs to be made.

**Response:**

48. For those samples collected in conjunction with possible sites such as those collected around Building 400, a correlation has been made. (Page 10.7.3)

**Comment:**

49. Page 11-6, Section 11.9 - Revise this section as needed, based upon the comments given above.

**Response:**

- 49. This section will be revised per the comment responses and the October 1996 meeting in Atlanta.**

**Comment:**

- 50. Page 13-1, Section 13.0 - The certification, required by regulation, is neither dated nor signed.**

**Response:**

- 50. The final document will include a dated and signed certification page.**

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## ABBREVIATIONS, ACRONYMS, AND SYMBOLS FOR NAVBASE ZONE C

The following abbreviations, acronyms, and units of measurement are used in this report.

AA	Atomic Absorption
ABF	Absorption Factor
AEC	Area of Ecological Concern
AL	Action Level
AOC	Area of Concern
AOI	Area of Interest
AQTESOLV	Aquifer Test Solver
ARAR	Applicable or Relevant and Appropriate Requirement
AST	Aboveground Storage Tank
ASTM	American Society for Testing and Materials
atm	Atmospheres
AWQC	Ambient Water Quality Criteria
BAF	Bioaccumulation Factor
BAP	Benzo(a)pyrene
BDL	Below Detection Limit
BE	Barometric Efficiency
BEHP	bis(2-ethylhexyl)phthalate
BEQ	Benzo(a)pyrene Equivalent
BEST	Building Economic Solutions Together
bgs	Below ground surface
BHC	Benzenhexachloride
BOD	Biochemical Oxygen Demand
BRA	Baseline Risk Assessment
BRAC	Base Realignment and Closure Act of 1988 and Defense Base Closure and Realignment Act of 1990, collectively
BTEX	Benzene, toluene, ethylbenzene, and xylene
CAMP	Corrective Action Management Plan
CAMU	Corrective Action Management Unit
CDD	Chlorinated dibenzo-p-dioxin
CDF	Chlorinated dibenzofuran
CDI	Chronic Daily Intake
CEC	Cation Exchange Capacity
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CF	Calibration Factor
CFR	Code of Federal Regulations
cm	centimeter
cm/sec	centimeters per second
CLEAN	Comprehensive Long-Term Environmental Action Navy

# **ABBREVIATIONS, ACRONYMS, AND SYMBOLS FOR NAVBASE ZONE C** **(Continued)**

CLP	Contract Laboratory Program
CM	Corrective Measures
CMI	Corrective Measures Implementation
CMS	Corrective Measures Study
COD	Chemical Oxygen Demand
CNS	Central Nervous System
CNSY	Charleston Naval Shipyard
COC	Chemical of Concern
COPC	Chemical of Potential Concern
cPAH	Carcinogen Polynuclear Aromatic Hydrocarbon
CPSS	Chemical Present in Site Samples
CRAVE	Carcinogen Risk Assessment Verification Endeavor
CRDL	Contract Required Detection Limit
CSAP	Comprehensive Sampling and Analysis Plan
CSI	Confirmatory Sampling Investigation
CT	Central Tendency
CV	Coefficient of Variation
CWA	Clean Water Act
DCAA	2,4-dichlorophenylacetic acid
DDD	Dichlorodiphenyldichloroethane
DDE	Dichlorodiphenyldichloroethylene
DDT	Dichlorodiphenyl-trichloroethane
DMA	Dredged Material Area
DNAPL	Dense Non-Aqueous Phase Liquid
DOD	Department of Defense
DQO	Data Quality Objectives
DRO	Diesel Range Organics
DWEL	Drinking Water Equivalent Level
E/A&H	EnSafe/Allen & Hoshall
ECAO	Environmental Criteria and Assessment Office
ECPC	Ecological Chemical of Potential Concern
EMPC	Estimated Maximum Possible Concentration
EOD	Explosive Ordnance Disposal
EPC	Exposure Point Concentration
ERA	Environmental Risk Assessment
ESA	Ecological Study Area
ESDSOPQAM	Environmental Services Division Standard Operating Procedures and Quality Assurance Manual

# **ABBREVIATIONS, ACRONYMS, AND SYMBOLS FOR NAVBASE ZONE C** **(Continued)**

FC	Fraction contracted
FFI	Focused Field Investigation
FI	Fraction Ingested
FID	Flameionization detector
ft <sup>2</sup> /day	Square feet per day
GC/MS	Gas Chromatography/Mass Spectroscopy
gpm	Gallons per minute
GPS	Global Positioning System
GRO	Gasoline Range Organics
HASP	Health and Safety Plan
HEAST	Health Effects Assessment Summary Table
HMW	High Molecular Weight
HI	Hazard Index
HQ	Hazard Quotient
HSWA	Hazardous and Solid Waste Amendments
HTTD	High-Temperature Thermal Desorption
ICAP	Inductively Coupled Argon Plasma
ICM	Interim Corrective Measure
ICP	Inductively Coupled Plasma
ID	Inside Diameter
IDL	Instrument Detection Limit
ILCR	Incremental Lifetime Excess Cancer Risk
ILO	Indeterminate Lubricating Oil
IRIS	Integrated Risk Information System
IRP	Installation Restoration Program
IS	Internal Standard
kph	Kilometers per hour
LCS	Laboratory Control Sample
LC <sub>50</sub>	Lethal Concentration to 50 percent of test population
LD <sub>50</sub>	Lethal Dose to 50 percent of test population
LDR	Land Disposal Restriction
LMW	Low Molecular Weight
LN	Natural Logarithm
LNAPL	Light Nonaqueous Phase Liquid
LQAC	Laboratory QA Coordinator
LTTD	Low-Temperature Thermal Desorption
MCL	Maximum Contaminant Level
MCLG	Maximum Contaminant Level Goal



# **ABBREVIATIONS, ACRONYMS, AND SYMBOLS FOR NAVBASE ZONE C** **(Continued)**

meq/L	Milliequivalent per liter
mg/kg	Milligram per kilogram
mg/L	Milligram per liter
mg/m <sup>3</sup>	Milligram per cubic meter
ml	Milliliter
mm	Millimeter
mph	Miles per hour
msl	Mean sea level
MS/MSD	Matrix Spike/Matrix Spike Duplicate
NA	Not Applicable
NAD	North American Datum
NAVBASE	Naval Base Charleston
NBS	National Bureau of Standards
NCEA	National Center for Environmental Assessment
NCR	NEESA Contract Representative
ND	Not Detected
NEESA	Naval Energy and Environmental Support Activity
NFI	No Further Investigation
ng/kg	Nanogram per kilogram
NGVD	National Geodetic Vertical Datum
NIOSH	National Institute for Occupational Safety and Health
NL	Not Listed
NOAA	National Oceanic and Atmospheric Administration
NOAEL	No Observable Adverse Effect Level
NPDES	National Pollutant Discharge Elimination System
NR	Not Reported
NTP	National Toxicology Program
NTU	Nephelometric Turbidity Unit
OERR	Office of Emergency and Remedial Response
OSHA	Occupational Safety and Health Administration
OSWER	Office of Solid Waste and Emergency Response
OVA	Organic Vapor Analyzer
PAH	Polynuclear Aromatic Hydrocarbon
PCB	Polychlorinated biphenyl
PDE	Potential Dietary Exposure
PE	Performance Evaluation
PEM	Performance Evaluation Mixture
pg/g	Picogram per gram

## ABBREVIATIONS, ACRONYMS, AND SYMBOLS FOR NAVBASE ZONE C (Continued)

pg/L	Picogram per liter
POTW	Publicly Owned Treatment Works
ppb	Parts per billion
PPE	Personal Protective Equipment
ppm	Parts per million
ppt	Parts per trillion
PRC	Preliminary Risk Characterization
PRG	Preliminary Remedial Goal
PSA	Preliminary Site Assessment
psi	Pounds per square inch
PVC	Polyvinyl Chloride
%R	Percent Recovery
%RSD	Percent Relative Standard Deviation
%D	Percent Difference
QA/QC	Quality Assurance/Quality Control
RAB	Restoration Advisory Board
RAD	Recommended Daily Allowance
RAGS	Risk Assessment Guidance for Superfund
RBC	Risk-Based Concentration
RBSL	Risk-Based Screening Level
RCRA	Resource Conservation and Recovery Act
RDA	Charleston Naval Complex Redevelopment Authority
RFA	RCRA Facility Assessment
RfC	Reference Concentration
RfD	Reference Dose
RFI	RCRA Facility Investigation
RGO	Remedial Goal Option
RME	Reasonable Maximum Exposure
RPD	Relative Percent Difference
RRF	Relative Response Factor
RTC	Reserve Training Center
RTV	Reference Toxicity Value
SAA	Satellite Accumulation Area
SAS	Special Analytical Services
SC	South Carolina
SCDHEC	South Carolina Department of Health and Environmental Control
SDG	Sample Delivery Group
SF	Slope Factor

# **ABBREVIATIONS, ACRONYMS, AND SYMBOLS FOR NAVBASE ZONE C** **(Continued)**

SFF	Site Foraging Factor
SMCL	Secondary Maximum Contaminant Level
SOP	Standard Operating Procedure
SOUTHDIV	Southern Division Naval Facilities Engineering Command
SPLP	Synthetic Precipitation Leaching Procedure
SQL	Sample Quantitation Limit
SSL	Soil Screening Level
SSV	Sediment Screening Value
SVE	Soil Vapor Extraction
SVOA	Semivolatile Organic Analysis
SVOC	Semivolatile Organic Compound
SWMU	Solid Waste Management Unit
TCDD	Tetrachlorodibenzo-p-dioxin
TD/MS	Thermal Desorption/Mass Spectrometry
TD-GS/MS	Thermal Desorption-Gas Chromatography/Mass Spectrometry
TDS	Total Dissolved Solids
TEF	Toxic Equivalency Factor
TEM	Transmission Electron Microscopy
TEQ	TCDD Equivalency Quotient
TOC	Total Organic Carbon
TPH	Total Petroleum Hydrocarbons
TSCA	Toxic Substances Control Act
TSS	Total Suspended Solid
TTAL	Treatment Technique Action Level
TU	Temporary Unit
UCL	Upper Confidence Limit
USDOT	United States Department of Transportation
USEPA	United States Environmental Protection Agency
UST	Underground Storage Tank
UTL	Upper Tolerance Limit
UV	Ultraviolet
UXO	Unexploded Ordinance
VOA	Volatile Organic Analysis
VOC	Volatile Organic Compound
WBZ	Water-Bearing Zone
WQC	Water Quality Control

**ABBREVIATIONS, ACRONYMS, AND SYMBOLS FOR NAVBASE ZONE C**  
**(Continued)**

$\mu\text{g}/\text{cm}^2$	Microgram per square centimeter
$\mu\text{g}/\text{g}$	Micrograms per gram
$\mu\text{g}/\text{kg}$	Microgram per kilogram
$\mu\text{g}/\text{L}$	Microgram per liter
2,4-D	2,4-dichlorophenoxyacetic acid
2,4-DB	2,4-dichlorophenoxybutyric acid
2,4,5-T	2,4,5-trichlorophenoxyacetic acid
2,4,5-TP	Silvex

## **1.0 INTRODUCTION**

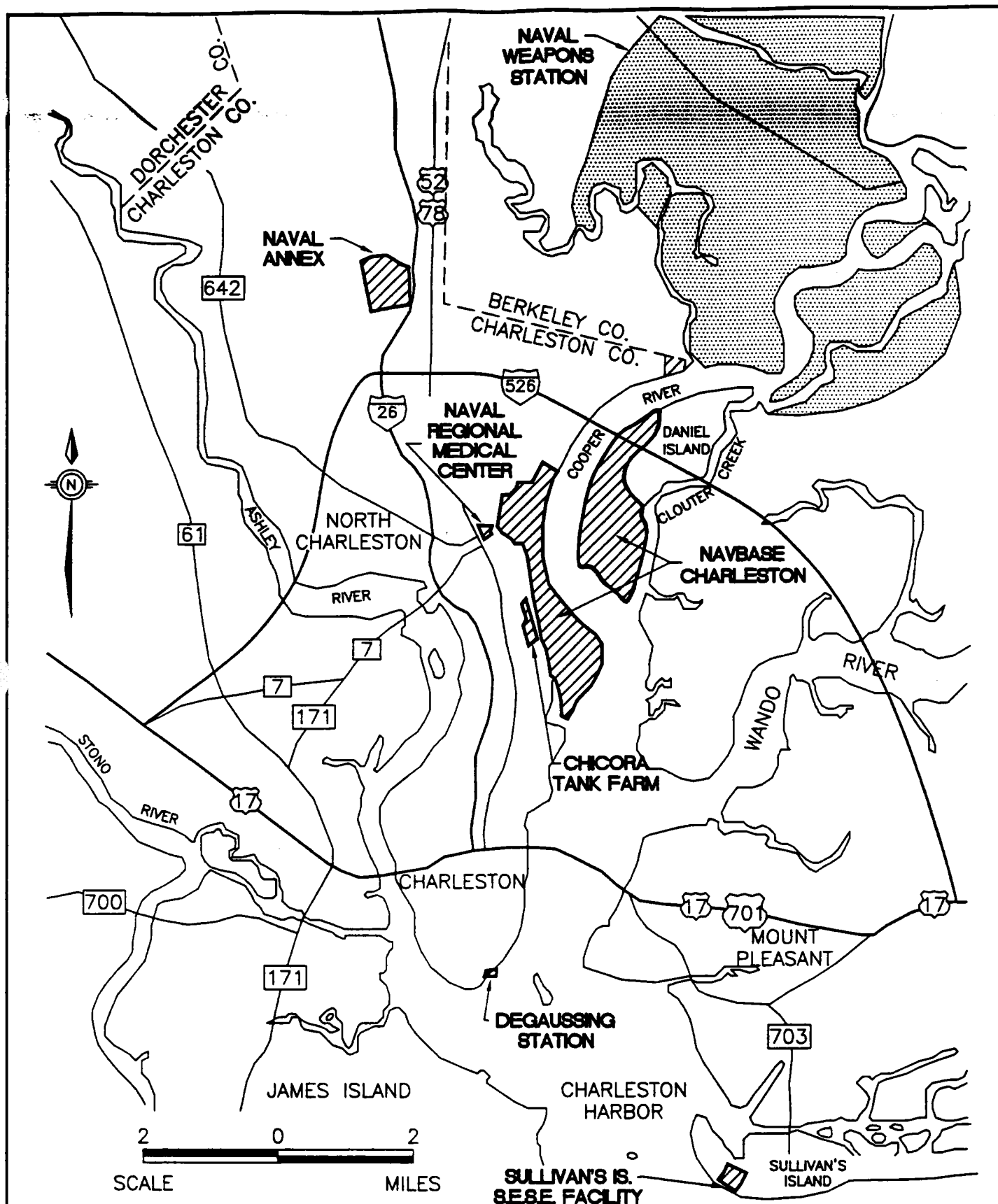
The environmental investigation and remediation at Naval Base Charleston (NAVBASE) are required by the Hazardous and Solid Waste Amendments (HSWA) portion of the Resource Conservation and Recovery Act (RCRA) Part B permit. These conditions are consistent with the RCRA Corrective Action Program, whose objectives are to evaluate the nature and extent of any hazardous waste or constituent releases, and to identify, develop, and implement appropriate corrective measures to protect human health and the environment. The scope of the RCRA Facility Investigation (RFI) includes the entire naval base, which has been divided into Zones A through L to accelerate the RFI process. This Zone C RFI Report, prepared by EnSafe Inc. (EnSafe), is submitted to satisfy condition II.C.6 of the HSWA portion of the Part B permit.

## **1.1 NAVBASE Description and Background**

### **Location**

NAVBASE is in the city of North Charleston, on the west bank of the Cooper River in Charleston County, South Carolina (Figure 1.1). This installation consists of two major areas: an undeveloped dredged materials area on the east bank of the Cooper River on Daniel Island in Berkeley County, and a developed area on the west bank of the Cooper River (Figure 1.1).

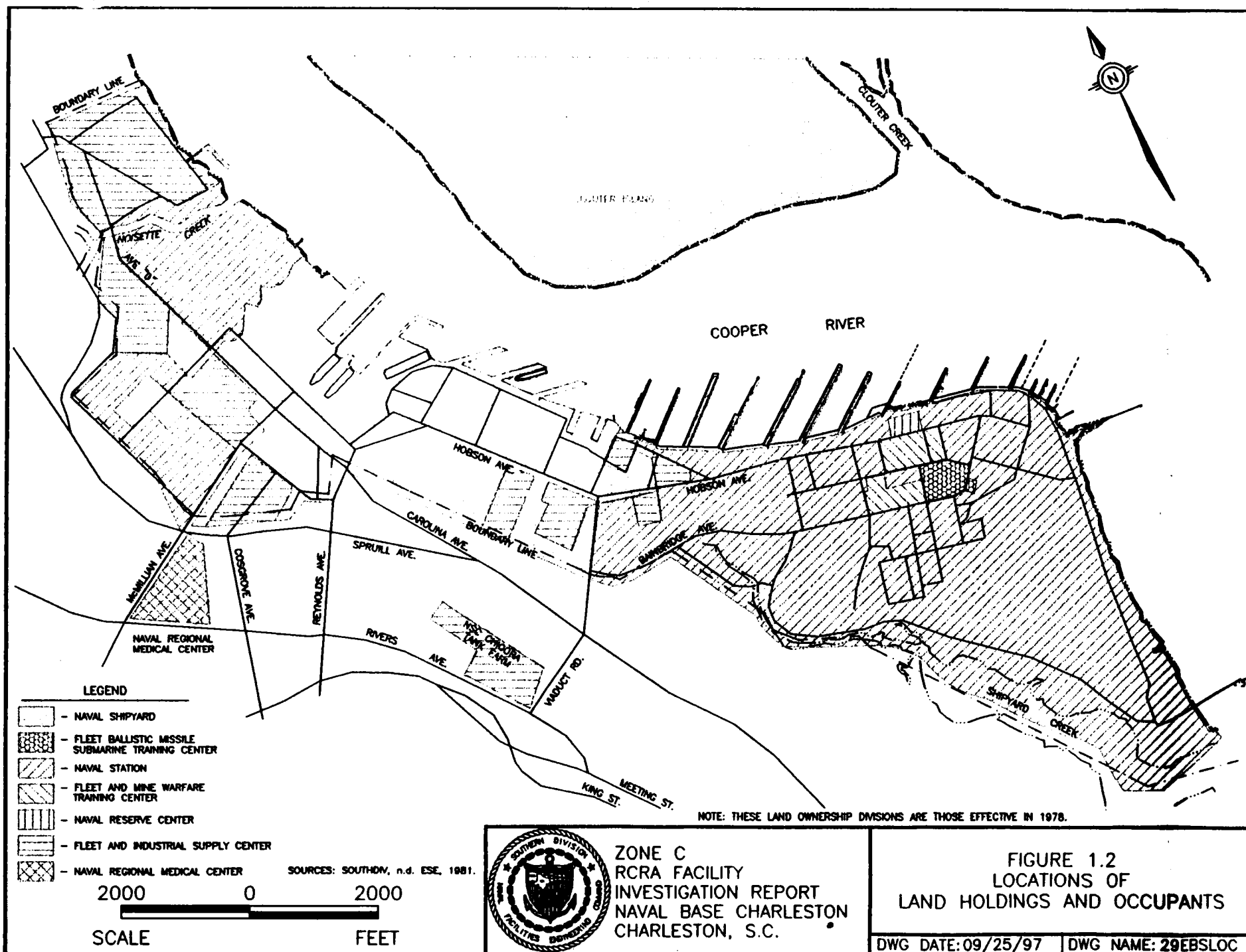
The developed portion of the base is on a peninsula bounded on the west by the Ashley River and on the east by the Cooper River. Major commands that formerly occupied areas of the base include Charleston Naval Shipyard, Fleet Ballistic Missile Submarine Training Center, Fleet and Industrial Supply Center, Fleet and Mine Warfare Training Center, Naval Hospital Charleston, and Naval Station (Figure 1.2). NAVBASE also included the degaussing facility in downtown Charleston, the Shipboard Electronics System Evaluation Facility on Sullivan's Island, and the Naval Station Annex adjacent to the Charleston Air Force Base.



ZONE C  
RCRA FACILITY  
INVESTIGATION REPORT  
NAVAL BASE CHARLESTON  
CHARLESTON, S.C.

FIGURE 1.1  
VICINITY MAP  
NAVAL BASE CHARLESTON  
CHARLESTON, SOUTH CAROLINA

DWG DATE: 09/30/97 | DWG NAME: 29EBSSAC



The areas surrounding NAVBASE are *mature urban*, having long been developed with commercial, industrial, and residential land uses. Commercial areas are primarily west of NAVBASE; industrial areas lie primarily north of NAVBASE and along the west bank of Shipyard Creek.

The area west of Shipyard Creek has been concentrated with industrial users for many years. Railways have served the area since the early 1900s. The presence of railways, when combined with nearby waterways, has made the area ideal for industry. While ownership has changed from time to time, the land adjacent to NAVBASE remains dedicated to chemical, fertilizer, oil refining, metallurgy, and lumber operations.

In contrast, the east bank of the Cooper River is undeveloped and contains extensive wetlands, particularly along Clouter Creek and Thomas Island. Active dredged materials disposal areas are on Navy property between the Cooper River and Clouter Creek.

## History

In 1901, the U.S. Navy acquired 2,250 acres near Charleston to build a naval shipyard, and the first naval officer was assigned duty in early 1902. A work force was organized, the navy yard surveyed, and construction of buildings and a drydock began. The drydock was finished in 1909, along with several other brick buildings and the main power plant, which are still in use today. With a work force of approximately 300 civilians, the first ship was placed in drydock and work began on fleet vessels in 1910. World War I brought about an expansion of the yard, land area, and work force. Employment levels dropped following the war. Work increased at the yard beginning in 1933, when a larger workload, principally in construction of several Coast Guard tugs, a Coast Guard cutter, and a Navy gunboat, created the need for more facilities and a much larger work force.



Civilian employment peaked in 1943 with almost 26,000 employees divided among three daily shifts. In 1956, construction began on new piers, barracks, and buildings for mine warfare ships and personnel. Later in the decade, Charleston became a major homeport for combatant ships and submarines of the U.S. Atlantic Fleet.

### **Base Closure**

Today, NAVBASE Charleston is in the process of shutting down operations. In 1993, NAVBASE Charleston was added to the list of bases scheduled for closure under the Defense Base Realignment and Closure Act (BRAC), which regulates the closure and transition of property to the community. Operations have been scaled back and environmental cleanup has begun to make the property available for redevelopment after closure on April 1, 1996.

## **1.2 Base Closure Process for Environmental Cleanup**

### **The Installation Restoration Program**

In 1980, the Department of Defense established the Installation Restoration Program (IRP) to investigate and clean up contamination which may have resulted from past operations, storage, and disposal practices at federal facilities around the country. The Navy adopted this program, which has regulatory requirements similar to those developed under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). Although federal installations were not required to comply with this act until it was amended in 1986, the Navy has, in effect, been complying with its environmental regulations through participation in the IRP since 1980.

### **Resource Conservation and Recovery Act**

The primary focus of NAVBASE environmental cleanup activities falls under RCRA, which was passed by Congress to control the handling of hazardous materials and wastes and to set standards for hazardous waste generation, transportation, treatment, storage, and disposal. NAVBASE was issued a hazardous waste permit in 1990 in accordance with this act, allowing the base to operate

within these guidelines. Hazardous materials include substances such as chemicals, pesticides, petroleum products, paints, and cleaners identified by the U. S. Environmental Protection Agency (USEPA) as being potentially harmful to human health or the environment.

The NAVBASE hazardous waste permit covers the investigation and cleanup of individual sites called solid waste management units (SWMUs) as well as areas of concern (AOCs) resulting from past hazardous waste spills. SWMUs and AOCs are defined in the Part B permit as follows:

- **SWMU** — "Any unit which has been used for the treatment, storage, or disposal of solid waste at any time, regardless of whether the unit is or ever was intended for the management of solid waste. RCRA-regulated hazardous waste management units are also solid waste management units. SWMUs include areas that have been contaminated by routine and systematic releases of hazardous constituents, excluding one-time accidental spills that are immediately remediated and cannot be linked to solid waste management activities (e.g., product or process spills)."
- **AOC** — "Any area having a probable release of a hazardous waste or a hazardous constituent which is not from a solid waste management unit and is determined by the Regional Administrator to pose a current or potential threat to human health or the environment. Such areas of concern may require investigations and remedial actions as required under Section 3005(c)(3) of the Resource Conservation and Recovery Act and 40 CFR §270.32(b)(2) in order to ensure adequate protection of human health and the environment."

Where appropriate in this document, SWMUs and AOCs are collectively referred to as *sites*.

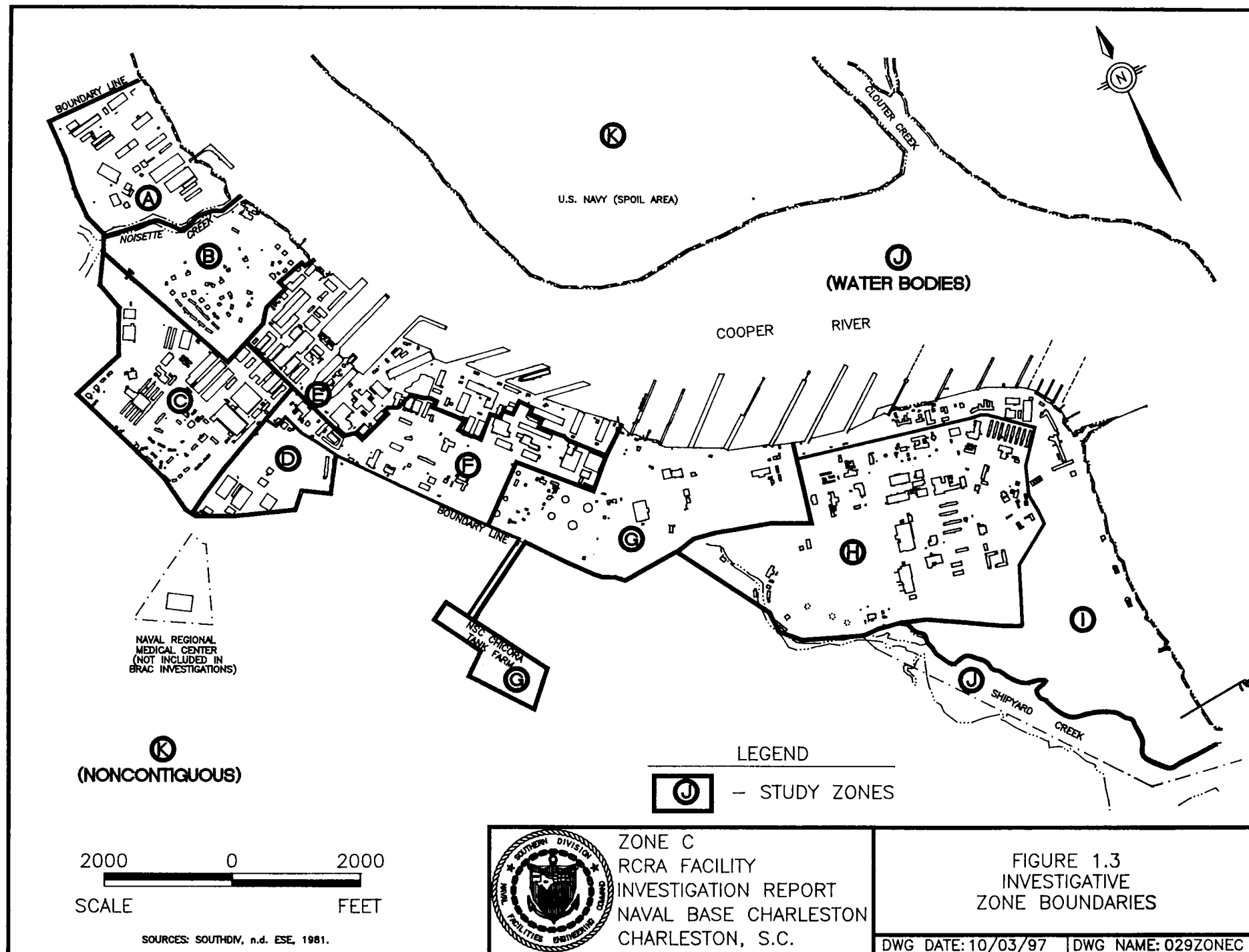
The investigation and cleanup activities are referred to as "corrective measures." The main steps of the corrective measures process are outlined below.

- *RCRA Facility Assessment (RFA)* identifies potential or actual contaminant releases through a records review and visual examination of every SWMU and AOC.
- *RCRA Facility Investigation (RFI)* confirms contamination and determines its nature. This investigation also examines the extent and rate of any migration and provides baseline data to evaluate corrective measures.
- *Corrective Measures Study (CMS)* determines and evaluates cleanup alternatives for the site. This study also recommends a preferred cleanup option or corrective measure.
- During *Corrective Measures Implementation (CMI)*, the selected corrective measure is designed, constructed, operated, maintained, and monitored for performance.
- *Interim Corrective Measures (ICMs)* are used to stabilize, control, or limit further releases from a site. Interim measures can be imposed at any point in the process.

### **1.3 Investigative Zone Delineation**

Due to the size of the base and the level of detail required for investigations, NAVBASE has been divided into 12 investigative zones, identified as A through L, as shown in Figure 1.3.

The zone investigations and cleanups were ranked by the Restoration Advisory Board and the BEST (Building Economic Solutions Together) committee (a board authorized by the state to study and report on the best reuse options for the property being transferred). In 1994, BEST was



replaced by the Charleston Naval Complex Redevelopment Authority, which has authority to establish leases for the transferred property. Zone C is on the western edge of the northern portion of NAVBASE. The zone is bounded by McMillian Avenue on the south; Hobson Avenue on the east; Avenue "D" on the northeast and the NAVBASE property boundary on the west and north. Zone C contains properties identified in the *Final Environmental Impact Statement for Disposal and Reuse of the Charleston Naval Base* (Ecology and Environment, Inc., June 1995) to be used for housing, open space/buffer, community support, and office/training.

#### **1.4 Current Investigation**

##### **Objective**

The objectives of the RFI are to characterize the nature and extent of contaminants associated with releases from SWMUs and AOCs, to evaluate contaminant migration pathways, and to identify both actual and potential receptors. The ultimate goal is to determine the need for ICMs or a CMS. This need will be evaluated by conducting a baseline risk assessment (BRA) to assess the risks posed to human health and the environment by individual and/or groups of sites within a zone.

##### **Scope**

Twenty-four sites were identified in Zone C through the RFA process. Each site in Zone C is detailed in the *Final RCRA Facility Assessment* (E/A&H, June 6, 1995).

Recommendations for investigative approach at each site were based on the best information available at that time and are subject to change should more information become available.

These investigatory designations are as follows:

- *No Further Investigation (NFI)* — This designation was applied to an AOC or SWMU if sufficient data were available during the RFA process to thoroughly assess the potential

hazards associated with the site and to determine that it does not pose a threat to human health or the environment.

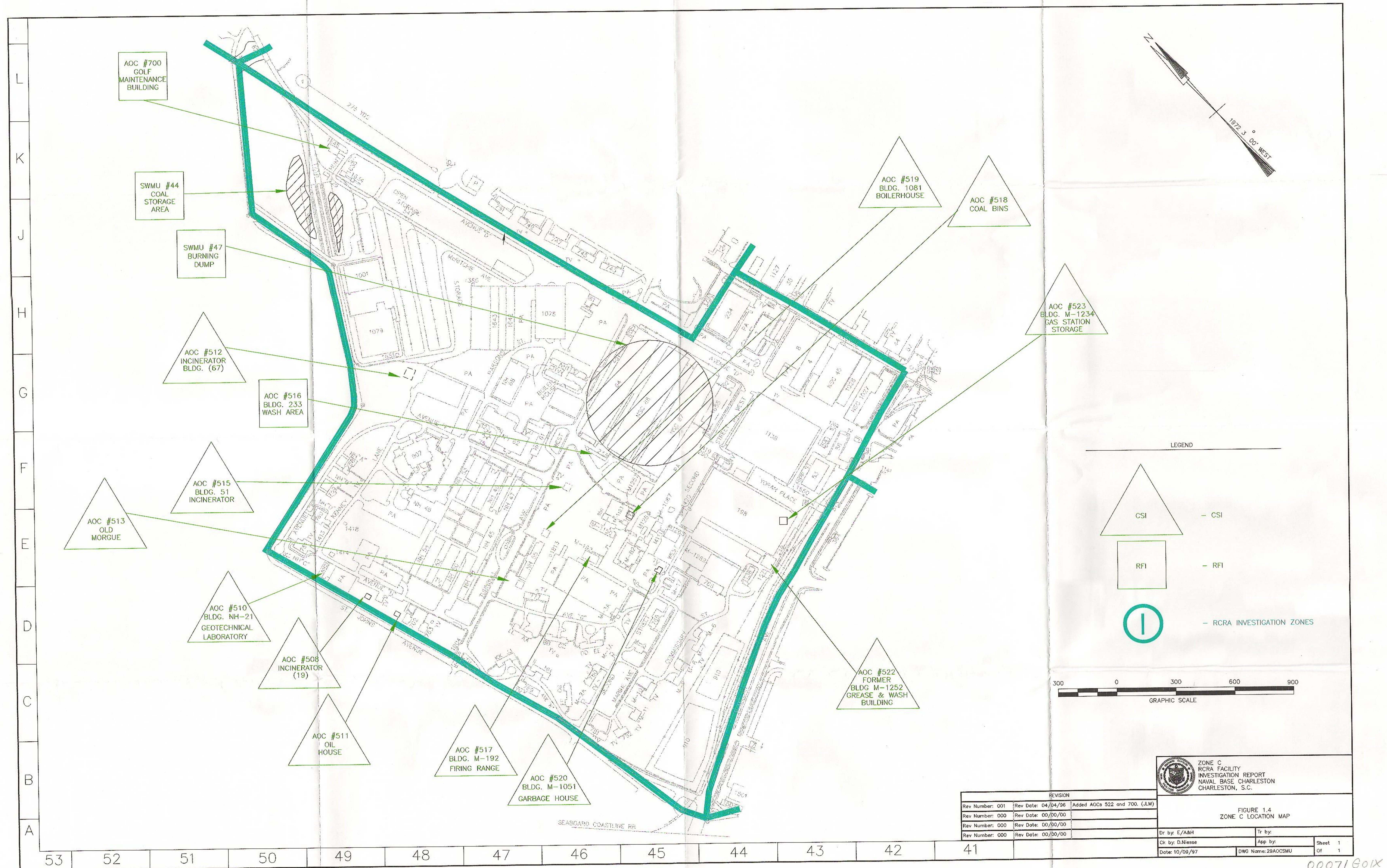
- *Confirmatory Sampling Investigation (CSI)* — This designation was applied to an AOC or SWMU if insufficient data were available during the RFA process to thoroughly assess the potential hazards associated with the AOC or SWMU. Generally, a limited amount of confirmatory samples are needed to determine whether a hazard exists. The result of the confirmatory sampling will determine whether no further investigation finding is appropriate or a full-scale RFI is warranted.
- *RFI* — This designation was applied to AOCs or SWMUs if visual evidence, historical information such as spill reports, or analytical data indicate that hazardous substances have been released to the environment. The RFI characterizes the site to determine the nature and extent of contamination, to identify migration pathways, to identify actual and potential receptors, and to evaluate the ecological and human health risks posed by the site.

Of the 24 SWMUs and AOCs identified in the RFA, 16 required further investigation. The *Final Zone C RFI Work Plan* (E/A&H, November 1995) outlined an investigative strategy for each site designated for a CSI or RFI. This RFI report only addresses sites included in the work plan and addendum. Table 1.1 summarizes each Zone C SWMU and AOC requiring further investigation and its investigative approach, and Figure 1.4 shows the SWMU and AOC locations.

## **1.5 Previous Investigations**

In addition to data generated during this investigation, information from previous Zone C investigations was reviewed for this report. Pertinent data have been incorporated where appropriate. A previous investigation at SWMU 44 included physical and confirmatory sampling.





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**Table 1.1**  
**Zone C SWMUs and AOCs with Investigatory Designations**

Zone C AOCs and SWMUs	Site Description	Investigative Approach	Investigation Grouping
SWMU 44	Coal Storage Area	RFI	Investigated independently
AOC 516	Wash Area/Battery Charging	RFI	AOC and SWMU were investigated together.
SWMU 47	Former Burning Dump	RFI	
AOC 508	Former Incinerator	CSI	AOCs were investigated together.
AOC 511	Former Oil Storehouse	CSI	
AOC 515	Former Incinerator and Paint Shop	CSI	AOCs were investigated together.
AOC 519	Former Boiler House	CSI	
AOC 510	Geotechnical Laboratory	CSI	Investigated independently
AOC 512	Former Incinerator	CSI	Investigated independently
AOC 513	Former Morgue	CSI	Investigated independently
AOC 517	Former Indoor Firing Range	CSI	Investigated independently
AOC 520	Former Garbage House	CSI	Investigated independently
AOC 522	Former Grease and Wash Area	CSI	Investigated independently
AOC 518	Former Coal Bins	CSI	Investigated independently
AOC 523	Former Gas Station	CSI	Investigated independently
AOC 700	Golf Course Maintenance Building	RFI	Investigated independently

Soil, surface water, and sediment samples collected were analyzed for metals and physical parameters.



## **1.6 RFI Report Organization**

To facilitate review of the RFI report, sections have been formatted to discuss zone-wide information, overall technical approach, and evaluation methodologies first. These general informational sections are sequenced according to the natural progression of an RFI investigation. The zone-wide sections are:

- 1.0 INTRODUCTION
- 2.0 PHYSICAL SETTING
- 3.0 FIELD INVESTIGATION
- 4.0 DATA VALIDATION
- 5.0 DATA EVALUATION AND BACKGROUND COMPARISON
- 6.0 FATE AND TRANSPORT
- 7.0 HUMAN HEALTH RISK ASSESSMENT
- 8.0 ECOLOGICAL RISK ASSESSMENT
- 9.0 CORRECTIVE MEASURES

The site-specific sections are:

- 10.0 SITE-SPECIFIC (SWMU and AOC) EVALUATIONS
- 11.0 CONCLUSIONS

and:

- 12.0 REFERENCES
- 13.0 SIGNATORY REQUIREMENT

Section 10 of the RFI Report follows the same chronology as Sections 1 through 9 (zone-wide) 1  
except on a site-specific (SWMU and AOC) basis. The section is subdivided by specific AOCs 2  
or SWMUs and includes the actual data summaries, risk calculations, and corrective measures 3  
evaluations specific to that site. In this manner, the entire investigation sequence, including 4  
conclusions, is contained within a specific tabbed section for easy reference. 5

Section 11 of the RFI Report summarizes the conclusion sections derived from each Section 10 6  
site-specific summary. In this manner, conclusions regarding which sites are recommended for 7  
the CMS and which are recommended for no further action can be easily determined. Section 12 8  
is a compilation of references. 9

## 2.0 NAVBASE PHYSICAL SETTING

### 2.1 Geology

#### 2.1.1 Regional Physiographic and Geologic Description

NAVBASE is in the Lower South Carolina Coastal Plain Physiographic Province, on the Cooper River side of the Charleston Peninsula, which is formed by the confluence of the Cooper and Ashley rivers. Topography in the area is typical of the South Carolina lower coastal plain, having low-relief plains broken only by the meandering courses of sluggish streams and rivers which flow toward the coast past occasional marine terrace escarpments. NAVBASE is essentially flat. Elevations range from just over 20 feet above mean sea level (msl) in the northwest part of the base to sea level at the Cooper River. Most of the original topography at NAVBASE has been modified by activities such as dredge spoil deposition. The southern end of the base was originally tidal marsh drained by Shipyard Creek and its tributaries. The original elevations in other portions of the base were only slightly higher. The land surface at NAVBASE has been elevated with both solid wastes and dredged materials (primarily the latter) in increments over the last 93 years. Nonetheless, most of NAVBASE remains within the 100-year flood zone of less than 10 feet above msl.

Charleston area geology is typical of the southern Atlantic Coastal Plain. Cretaceous and younger sediments thicken seaward and are underlain by older igneous and metamorphic basement rock. Surface exposures at NAVBASE, in the limited areas which remain undisturbed, consist of recent and/or Pleistocene sands, silts, and clays of high organic content referred to as the Wando Formation (Weems and Lemon, 1993). Underlying the Wando Formation, increasing with age, are the Oligocene-age Cooper Group and the Eocene-age Santee Limestone. The Cooper Group consists of the Parker's Ferry, Ashley, and Harleyville formations. The formation of particular importance in the Cooper Group is the Ashley Formation, which was formerly referred to as the Cooper Marl in most NAVBASE reports and regional geologic literature. In more recent geologic nomenclature, the name *Cooper* has been given to a group of formations

which includes the Ashley Formation, which is a pale-green to olive-brown, sandy, phosphatic limestone or marl, locally muddy and/or sandy. The Ashley Formation in the vicinity of Charleston is encountered at a depth of approximately 30 to 70 feet below ground surface (bgs). The relief of the top of the Ashley Formation is associated with an erosional basin (Park, 1985). Park identifies the entire Cooper Unit, of which the Ashley Formation is a member and hydrogeologically similar, as being approximately 300 feet thick.

Surface soil at NAVBASE has been extensively disturbed. Native soil is the fine-grained silts, silty sands, and clay typical of terrigenous tidal marsh environments. Sand lenses are present in localized areas; however, these are generally only a few feet thick. Much of NAVBASE has been filled using dredged materials from the Cooper River and Shipyard Creek. The dredged materials are an unsorted mixture of sands, silts, and clays.

### **2.1.2 NAVBASE Geologic Investigation**

Geological and stratigraphic information has been obtained from soil and monitoring well borings installed during the RFIs for Zones A, B, E, and C. Data for the Zone C investigation have been assessed and are included in the geologic and hydrogeologic assessment presented in this report. The soil was classified and logged by an EnSafe geologist as described in the Final RFI Comprehensive Sampling and Analysis Plan (CSAP), (E/A&H, August 1994). Shelby tubes collected during soil sampling were analyzed for porosity, grain size, and vertical permeability.

Two phases of drilling and well installation occurred during the Zone C RFI. The initial phase occurred between March and April 1995 with the installation of 26 shallow wells and two shallow/deep well pairs. After collecting and evaluating the groundwater and soil data from the initial investigation, a second shallow well installation phase took place in August 1997. In all, four temporary shallow wells were installed at AOCs 508, 511, and 512. Additionally, two deep soil borings were drilled to the top of the Ashley Formation at SWMU 44 for lithologic data (044SB027 and 044SB028).

Monitoring well construction data are summarized in Table 2.1. Figure 2.1 presents all Zone C well locations. Monitoring well construction diagrams and associated lithologic boring logs are included in Appendix A.

**Table 2.1**  
**Zone C Monitoring Well Construction Data**

Monitoring Well ID	Date Installed	TOC Elev. (msl)	Grnd. Elev. (msl)	Drilled Data (feet bgs)			DTW (TOC)	GW Elev.* (msl)
				TOS	BOS	BOW		
Zone C RFI Monitoring Wells								
NBCC044001	3/29/95	11.70	9.3	2.0	12.0	12.0	4.82	7.18
NBCC044002	3/29/95	11.20	8.9	3.1	13.1	13.1	7.23	5.87
NBCC044003	3/29/95	11.14	9.1	3.0	13.0	13.0	7.23	5.77
NBCC044004	3/30/95	10.95		4.3	14.3	14.4	7.11	7.29
NBCC044005	3/30/95	7.77	5.5	3.6	13.6	14.5	4.38	10.12
NBCC044006	3/30/95	7.75	5.3	2.0	12.0	12.0	2.78	9.22
NBCC044007	4/3/95	9.74	7.3	2.9	12.9	12.9	8.02	4.88
NBCC044008	4/3/95	11.13	8.7	3.4	13.4	13.5	6.03	7.47
NBCC047001	4/11/95	8.35	8.3	2.9	12.9	12.9	4.17	8.73
NBCC047002	4/6/95	9.80	10.1	3.0	13.0	13.0	6.67	6.33
NBCC047003	4/10/95	9.26	9.1	2.9	12.9	12.9	6.12	6.78
NBCC047004	4/10/95	9.08	9.2	2.5	12.5	12.5	5.54	6.96
NBCC047005	4/5/95	11.14	8.7	2.0	12.0	12.0	7.30	4.70
NBCC047006	4/5/95	12.27	9.8	2.1	12.1	12.1	7.53	4.57
NBCC047007	4/12/95	9.28	9.4	2.5	12.5	12.5	4.47	8.03
NBCC047008	4/12/95	9.16	9.4	2.6	12.6	12.6	4.58	8.02
NBCC047009	4/11/95	8.62	8.8	2.9	12.9	12.9	4.45	8.45
NBCC047010	4/12/95	8.30	8.4	2.6	12.6	12.6	4.09	8.51
NBCC047011	4/10/95	8.21	8.3	2.6	12.6	12.6	4.60	8.00
NBCC047012	4/10/95	8.56	8.6	2.9	12.9	12.9	5.15	7.75
NBCC047013	4/17/95	9.25	9.3	2.5	12.5	15.0	5.66	9.34
NBCC047015	4/17/95	8.96	9.1	2.5	12.5	15.0	4.92	10.08
NBCC510001	4/4/95	29.16	27.0	11.0	21.0	21.0	17.82	3.18
NBCC510002	4/5/95	28.30	26.3	11.0	21.0	21.0	17.27	3.73
NBCC523001	4/4/95	7.89	8.3	2.5	12.5	12.6	4.63	7.97
NBCC523002	4/4/95	9.10	9.5	2.4	12.4	12.4	5.40	7.00
NBCCGDC001	3/28/95	26.98	25.4	3.5	13.5	14.0	12.05	1.95
NBCCGDC01D	4/4/95	11.45	24.8	26.0	36.0	36.0	12.66	23.34
NBCCGDC002	3/29/95	27.69	9.0	2.0	12.0	14.0	7.29	6.71
NBCCGDC02D	4/5/95	11.17	9.3	61.0	71.0	9.3	7.84	1.46

**Table 2.1**  
**Zone C Monitoring Well Construction Data**

Monitoring Well ID	Date Installed	TOC Elev. (msl)	Grnd. Elev. (msl)	Drilled Data (feet bgs)			DTW (TOC)	GW Elev.* (msl)
				TOS	BOS	BOW		
Temporary Monitoring Wells								
NBCC508003	8/7/97	29.44	26.9	9.5	19.2	19.5	13.78	15.66
NBCC511002	8/6/97	29.09	26.6	10.0	19.7	20.0	12.34	16.75
NBCC512002	8/7/97	10.23	7.9	2.0	11.7	12.0	3.83	6.40
NBCC512003	8/7/97	12.38	10.0	3.0	12.7	13.0	5.21	7.17
Zone E RFI Monitoring Wells								
NBCEGDE027	9/11/96	10.19	7.2	3.0	12.0	13.0	6.98	3.21
NBCEGDE27D	9/12/96	9.79	7.2	28.2	37.2	38.0	6.59	3.20
NBCEGDE028	9/13/96	9.62	9.7	3.8	12.8	13.8	7.02	2.60
NBCEGDE28D	9/10/96	9.52	12.3	21.7	25.7	26.5	6.79	2.73

**Notes:**

bgs = below ground surface

msl = mean sea level

TOC = Top of well casing

TOS = Top of screened interval

BOS = Bottom of screened interval

DTW = Depth to water

\* = Depths to groundwater vary seasonally and diurnally. These depths should only be considered approximate (6/21/95 data presented for Zone C wells; 8/8/97 data presented for Zone C temporary wells; 10/16/96 data presented for Zone E wells).

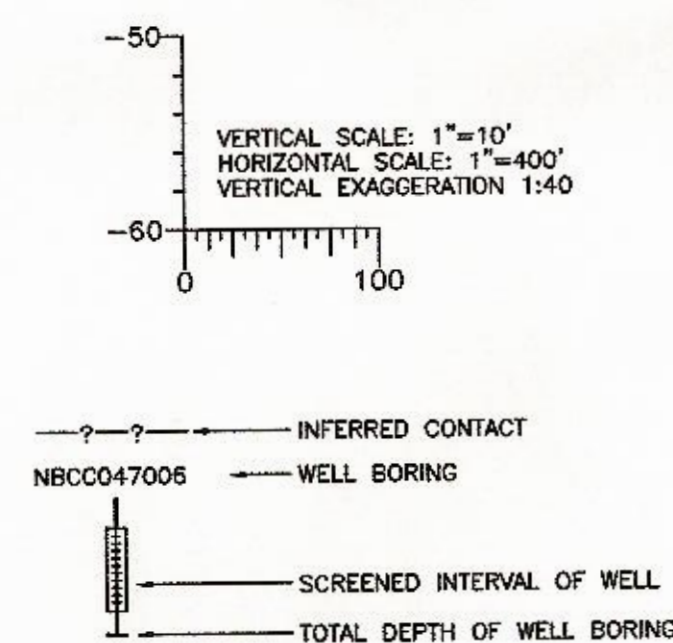
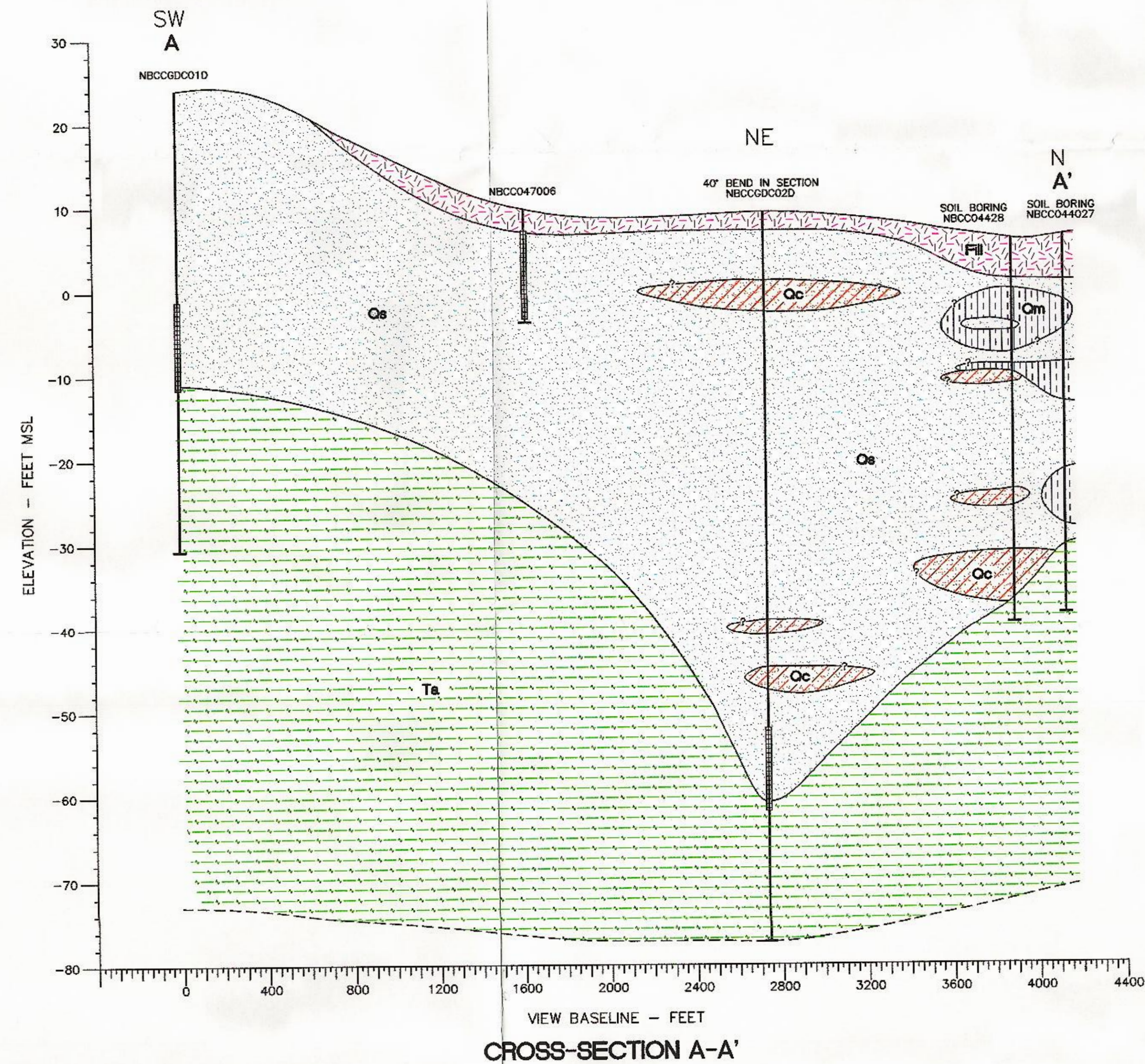
Two shallow/deep well pairs, NBCEGDE027/27D and NBCEGDE028/28D, drilled during the Zone E RFI, and are located within the southeastern portion of Zone C. Lithologic data from these two borings as well as those within Zone B were considered in evaluating the subsurface geology of Zone C. Please refer to the *Final RFI Report CTO-0029 Zone B* (E/A&H, November 1996) and *Draft Zone E RFI Report* (E/A&H, November 1997) for boring log data for these additional locations.

Of the stratigraphic formations described in Section 2.1.1, the two most prominent formations encountered were the Wando and Ashley formations. The lowermost stratigraphic unit identified is the Ashley Formation of the Tertiary Cooper Group. The bulk of the sediments overlying the

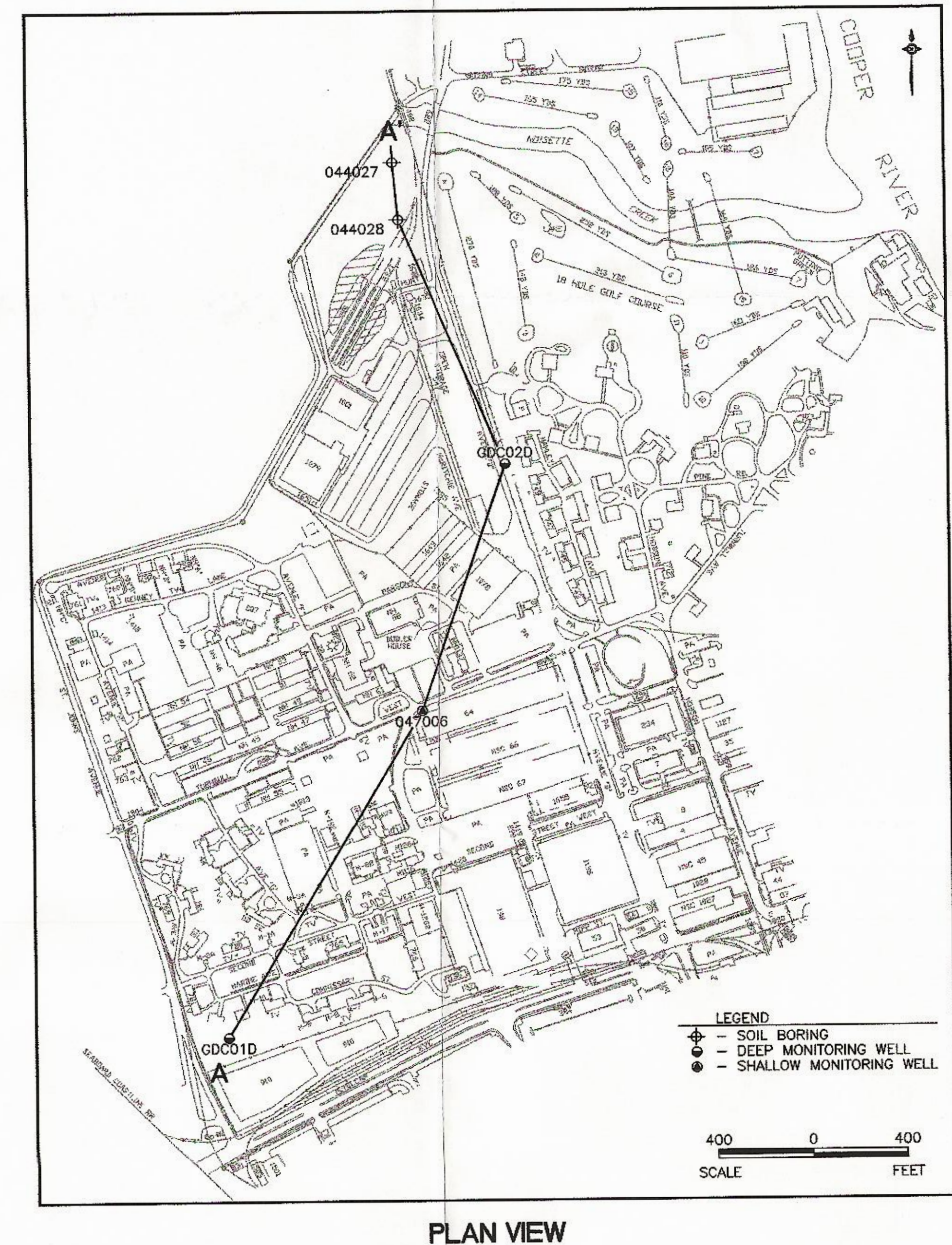








LEGEND	
Fill	Undifferentiated mixture of medium to high plasticity clays, fine sand, silt, gravel and ROC. Varies greatly with location.
Qc	QUATERNARY CLAY--light gray to green-gray with occasional mottling of orange or red; medium plasticity; typically stiff; some very fine to fine sand present usually in matrix; no organic material.
Qm	QUATERNARY MARSH CLAY--gray to black; highly organic; low to medium plasticity; soft; silty; occasional very fine to fine sand present as stringers and laminas; also occurs as older, more compacted and stiff marsh clay deposits at depth.
Qs	QUATERNARY SAND--light brown to gray; predominantly very fine to fine with occasional gradations of medium to coarse grain fractions; occasional shell hash and phosphatic nodules.
Ta	TERTIARY ASHLEY FORMATION--olive-green to olive-brown silt with varying amounts of clay and very fine sand, medium plasticity, firm to stiff, trace calcareous.
	CONFINING UNIT.



REVISION		
Rev Number:000	Rev Date:00/00/00	Rev By: NAME
Rev Number:000	Rev Date:00/00/00	Rev By: NAME
Rev Number:000	Rev Date:00/00/00	Rev By: NAME
Rev Number:000	Rev Date:00/00/00	Rev By: NAME
Rev Number:000	Rev Date:00/00/00	Rev By: NAME
Rev Number:000	Rev Date:00/00/00	Rev By: NAME

		ZONE C FINAL RCRA FACILITY INVESTIGATION REPORT NAVAL BASE CHARLESTON CHARLESTON, S.C.	
FIGURE 2.2 LITHOLOGIC CROSS SECTION A-A'			
Dr by: E. ROGERS	Tr by: E. ROGERS	App by: A. DENNEN	Sheet 1
Chk by: T. KAFKA	Date: 10/06/97	DWG Name: 2903LCSA	Of 1

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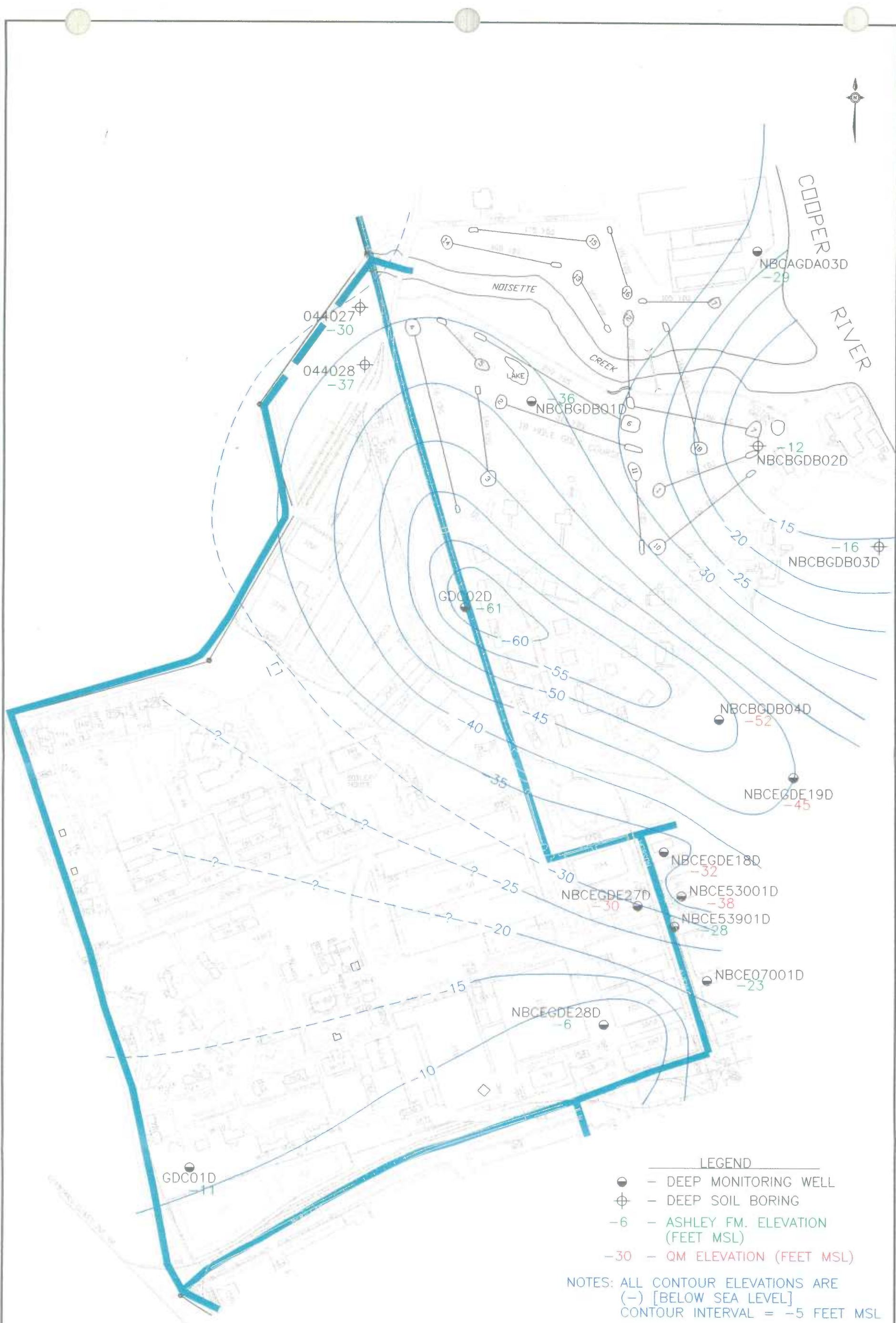
Ashley are thought to make up the Quaternary Wando Formation. However, several different Quaternary-age units are physically similar to the Wando and cannot be unequivocally identified in the field. There is also the possibility of Quaternary-age reworking of Tertiary sediments. As a result, the deposits encountered overlying the Ashley were lumped into Quaternary-age groupings.

Borehole lithologic information in Zone C is limited the information to the upper 85 feet of the subsurface. Boring data were used to construct a lithologic cross section A-A' across Zone C (Figure 2.2). Additional boring data from Zones A, B, and E deep well locations were used to construct a contour map of the elevation of the top of the confining unit, which is primarily the Ashley Formation for most of Zone C (Figure 2.3).

### **2.1.3 Ashley Formation (Ta)**

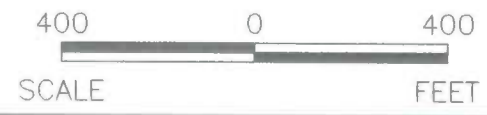
The Ashley Formation was encountered in all Zone C deep borings. The top of this formation, which was the target of deep borings, was encountered from -6.1 feet msl and -60.7 feet msl at locations GDE28D and GDC02D, respectively. The significant relief of its surface is clearly evident in Figures 2.2 and 2.3. Shallow elevations of the Ashley exist in the southern portion of the zone and decrease towards the north. A depression in the Ashley is located in the vicinity of GDC02D.

The Ashley Formation is an olive-yellow to olive-brown, tight, calcareous, sandy and clayey silt often found dry in split-spoon samples. A sample collected for physical parameter analysis from the Ashley Formation at GDC02D was composed of 26% sand, 47% silt, and 27% clay. Five Ashley Formation samples collected in Zone H for grain-size analysis revealed an average silt, sand, and clay content of 49%, 27%, and 27%, respectively. Geotechnical information for the physical parameter samples collected in Zone C is presented in Appendix B.



- LEGEND
- - DEEP MONITORING WELL
  - ⊕ - DEEP SOIL BORING
  - 6 - ASHLEY FM. ELEVATION (FEET MSL)
  - 30 - QM ELEVATION (FEET MSL)

NOTES: ALL CONTOUR ELEVATIONS ARE (-) [BELOW SEA LEVEL]  
 CONTOUR INTERVAL = -5 FEET MSL



ZONE C  
 RCRA FACILITY  
 INVESTIGATION REPORT  
 NAVAL BASE CHARLESTON  
 CHARLESTON, S.C.

FIGURE 2.3  
 ZONE C  
 TOP OF CONFINING UNIT  
 ELEVATION CONTOUR MAP  
 DWG DATE: 10/09/97 DWG NAME: 2903TCUE

00071B04Z

#### 2.1.4 Quaternary-Age Sediments

Overlying the Ashley Formation in Zone C and extending to ground surface (in areas not covered by fill materials) are Quaternary-age sediments which range in thickness from approximately 16 to 70 feet at GDE28D and GDC02D, respectively. Four Shelby tube samples were collected from the near surface (< 20 feet bgs) Quaternary-age sediments underlying Zone C. The average porosity for these samples was 35%. The grain-size distribution for these samples averaged 96% sand, 3% silt, and 1% clay.

The Quaternary-age deposits introduced in Figure 2.2 consisted of three lithologic units, which are briefly summarized as follows:

- Quaternary-age clay (Qc): Light gray to green-gray with occasional orange and red mottling; medium plasticity; typically stiff; some very fine to fine sand present usually in matrix; no organic material.
- Quaternary-age marsh clay (Qm): Gray to black; highly organic; low to medium plasticity; soft; silty; occasional very fine to fine sand present as stringers and laminae; also occurs as older, more compacted and stiff, dewatered marsh clay deposits at depth.
- Quaternary-age sand (Qs): Light brown to gray; predominantly very fine to fine with occasionally gradations of medium to coarse grain fractions; occasional shell hash and phosphate nodules.

The Qs unit is the most predominant of the Quaternary-age units found in Zone C. The Qm and Qc deposits have limited lateral continuity and are primarily localized. The greater concentration of Qm deposits to the north reflects the marsh environment associated with Noisette Creek.

The boring log for GDC01D illustrates the lithology encountered in the extreme southwestern portion of Zone C. Fine sand was present in this well from the surface to 15 feet bgs. From 15 to 26 feet bgs, the lithology is primarily sandy clay, although clay content decreases over the last 2 to 3 feet. A well-sorted, medium to coarse grained shell hash was present from 26 to 29 feet bgs, which was underlain by another 7 feet of fine sand to 36 feet bgs. The Ashley Formation was encountered at the base of this sand.

A significant variation in lithologic composition was encountered at GDE27D in the southeastern portion of the zone. Beneath the upper 5 feet of fill (clay and unconsolidated sand), a 20-foot section of very fine to fine sand (Qs) with some medium-grained lenses and silty sections was encountered. Rapidly interbedded fine-grained silty sand and clay laminae were present from 25 to 35 feet bgs, followed by more than 2 feet of poorly sorted, fine to coarse sand with shell fragments and black phosphate fragments to approximately 37 feet bgs. Older, compacted marsh clay (Qm) was present from 37 feet bgs to the top of the Ashley Formation at 40 feet bgs.

The boring log for GDC02D illustrates the lithology encountered along the Zone C and B boundary in the vicinity of the depression in the Ashley Formation shown in Figures 2-2 and 2-3. The interval between ground surface and the top of the Ashley Formation at GDC02D is primarily fine to medium-grained sand (Qs), except for three deposits of stiff, gray clay (Qc) present at 8 to 12 feet bgs, 49-50 feet bgs, and 54-57 feet bgs. From 57 feet bgs to the top of the Ashley Formation at 70 feet bgs, sand (Qs) with increased silt and clay content was present. A sample collected for physical parameter analysis from 54 to 70 feet bgs was composed of 78% sand, 10%

silt, and 12% clay. The depth of sand development at this location reflects the extensive erosion of the Ashley Formation during the Quaternary period.

### **2.1.5 Soil**

The extent of fill materials in Zone C reflects topographical relief within the zone. Fill materials were not encountered along the southwestern and western portions of the zone, which are higher in elevation and are primarily residential. Lower elevations to the east, southeast, and northeast (near Noisette Creek) are closer in elevation to sea level and have a greater preponderance of fill materials in the upper 5 to 10 feet of the shallow subsurface.

## **2.2 NAVBASE Hydrogeology**

### **2.2.1 Regional Hydrologic and Hydrogeologic Background**

Parts of the southern portion of NAVBASE are drained by Shipyard Creek, while northern areas are drained by Noisette Creek. The drainage basins of both waterways include areas other than NAVBASE. These waterways are tributaries to the Cooper River. Surface drainage over the remainder of NAVBASE flows directly into the Cooper River, which discharges into Charleston Harbor.

Shipyard Creek, a small tidal tributary about 2 miles long, flows southeast along the southwestern boundary of NAVBASE to its confluence with the Cooper River opposite the southern tip of Daniel Island. Piers line the western shore of the channel's lower mile, while the entire length of the eastern shore is bounded by tidal marshland.

Noisette Creek, which transects the northern portion of NAVBASE, is a tidal tributary approximately 2.5 miles long. The creek flows nearly due east from its headwaters in the City of North Charleston and empties into the Cooper River.

Groundwater occurs under water table or poorly confined conditions within the Pleistocene deposits overlying the Ashley Formation. Transmissivities in the Pleistocene aquifer are generally less than 1,000 square feet per day (feet<sup>2</sup>/day) and well yields are variable, ranging from 0 to 200 gallons per minute (gpm). This groundwater contains high concentrations of iron and is commonly acidic at shallow depths (Park, 1985).

The Ashley Formation is hydrogeologically significant mainly because of its low permeability. In most locales, its sandy, finely granular limestones produce little or no water and act as confining material that produces artesian conditions in the underlying Santee Limestone (Park, 1985).

The Santee Limestone aquifer is typically artesian, except in outcrop areas. Yields from wells in the Santee are typically less than 300 gpm (Park, 1985).

### **2.2.2 NAVBASE Hydrogeologic Investigation**

Hydrogeological information was obtained from slug test analysis and water level measurements conducted during the Zone C RFI. Vertical permeability, grain-size distribution, and porosity were estimated from analysis of Shelby tube samples collected during drilling.

### **2.2.3 Lower Confining Unit**

The high clay and silt content, laterally consistent overall thickness, and very low vertical permeabilities of the Ashley Formation indicate that this formation behaves as a confining unit beneath much of Zone C. Zone H Shelby tube samples collected from the Ashley exhibited a very low average vertical hydraulic conductivity of 0.0027 feet per day. According to Fetter (1988), sediments with permeabilities of  $10^{-5}$  centimeters per second (cm/sec) (0.03 feet/day) or less can be considered confining units. The low vertical permeability in the Ashley indicates an extremely low potential for groundwater movement downward through the unit. The fact that samples collected from this formation were dry to moist lends further credence to its designation as an

aquitard. As a confining unit, the Ashley behaves as a hydraulic barrier between the water-bearing Quaternary-age sediments and underlying formations.

As shown in Figure 2.3, the Ashley Formation was not encountered at several locations close to the Zone C boundary in Zone E (NBCEGDE18D and NBCE53001D) and Zone B (NBCBGDB04D); instead, older, compacted deposits of marsh clay (included as Qm deposits in the Zone C lithologic unit classification) were found. Samples of this unit from the Zone E RFI (classified as Qco in the *Draft Zone E RFI Report*) had an average vertical permeability of  $2.16 \times 10^{-6}$  cm/s (0.0061 feet/day) and averaged 4.5% sand and 95.4% silt and clay. These physical characteristics are similar to those of the Ashley, indicating that the older, compacted and dewatered Qm deposits also behave as a confining unit, although localized in extent. At GDE27D, 3 feet of Qm was found overlying the Ashley, indicating that the unit pinches out to the west. Therefore, it is thought that the confining unit beneath all but the extreme southeastern corner of Zone C is the Ashley Formation.

#### 2.2.4 Surficial Aquifer

The high sand content (approximately 90%) and moderate vertical permeability of the Quaternary-age units found in Zone C indicate that this formation is an aquifer. Shelby tube samples collected from this formation exhibited a moderate average vertical hydraulic conductivity of 2.1 feet/day. According to Anderson (1990) and Fetter (1988), sediments with permeabilities between 1 and 10 feet per day and greater than 0.03 feet/day are defined as unconfined fine sand with water-transporting capabilities.

The surficial aquifer primarily behaves as an unconfined aquifer throughout Zone C. Shallow wells monitor fluctuations of the water table, which was generally encountered within 6 feet bgs. Deep wells, in the absence of any aquitards, monitor hydrostatic pressure of the unconfined aquifer for that portion of the aquifer immediately overlying the confining unit. The presence of

Qc and Qm deposits may result in locally semi-confining conditions in Zone C, primarily in areas of greater clay development (i.e., Noisette Creek and SWMU 44). Localized semi-confined conditions are probably prevalent at GDC02D based on the 3-foot thick Qc deposit located approximately 5 feet above the top of the well screen (Figure 2.2).

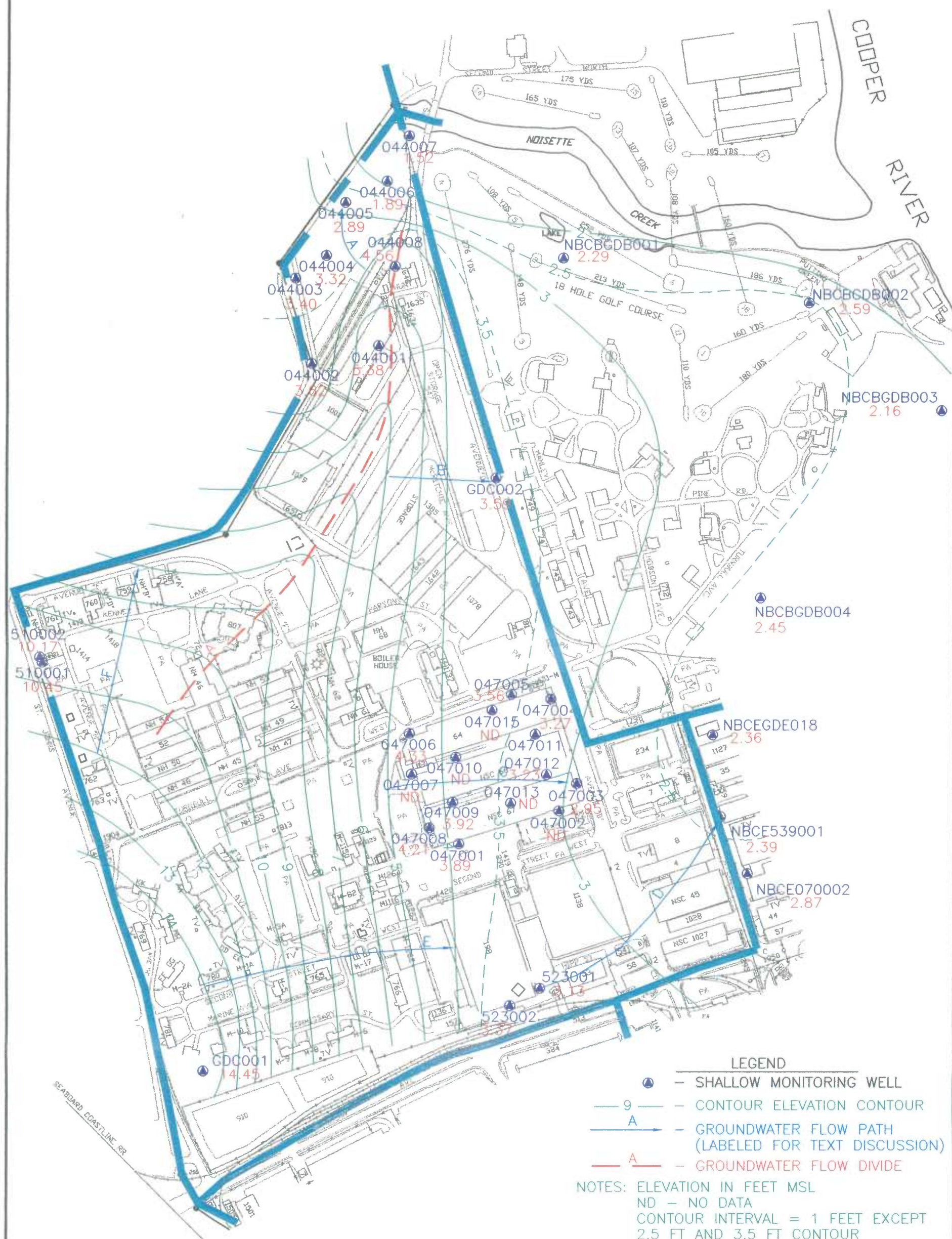
### **2.2.5 Groundwater Flow Direction**

Groundwater levels in Zone C wells were measured as part of a base-wide water level measurement event on June 28, 1996. Since the shallow well screens intersect the water table, groundwater elevations measured in shallow wells represent the water table surface. A groundwater elevation map using the shallow well data is presented in Figure 2.4; it includes several Zone B and E wells to further define the geometry of the water table surface. Four wells at SWMU 47 were inaccessible during this event and are labeled "ND" for no data in Figure 2.4. Intermediate contours representing the 2.5 and 3.5-foot elevations were included to further define the hydraulic head domain.

Groundwater elevations are highest in the west and southwestern portion of Zone C. A groundwater divide (labeled "A" in Figure 2.4) trends roughly southwest to northeast and separates the northwestern and southeastern portion of the zone. Groundwater northwest of divide "A" either flows off NAVBASE property or toward SWMU 44. Southeast of divide "A" groundwater flows east toward Zones B and E.

A Zone C deep well groundwater elevation map was not constructed due to the limited number and spacing of deep wells. The deep wells will, however, be used in developing base-wide groundwater elevation maps.





ZONE C  
 RCRA FACILITY  
 INVESTIGATION REPORT  
 NAVAL BASE CHARLESTON  
 CHARLESTON, S.C.

FIGURE 2.4  
 ZONE C  
 SHALLOW GROUNDWATER ELEVATION  
 MAP - JUNE 28, 1996  
 DWG DATE: 10/03/97 DWG NAME: 2903SGEM

000716052



## 2.2.6 Vertical Hydraulic Gradient

When water levels at the two shallow/deep well pairs in Zone C are compared, one well pair exhibited a positive hydraulic gradient and the other a negative gradient. Positive gradients indicate a downward potential for vertical flow and negative gradients indicate potential for upward flow.

Table 2.2 presents the calculated vertical hydraulic gradients between the shallow/deep well pairs. The vertical gradients were calculated by dividing the differences between shallow and deep water level elevations by the vertical distance between the bottom of the well screens.

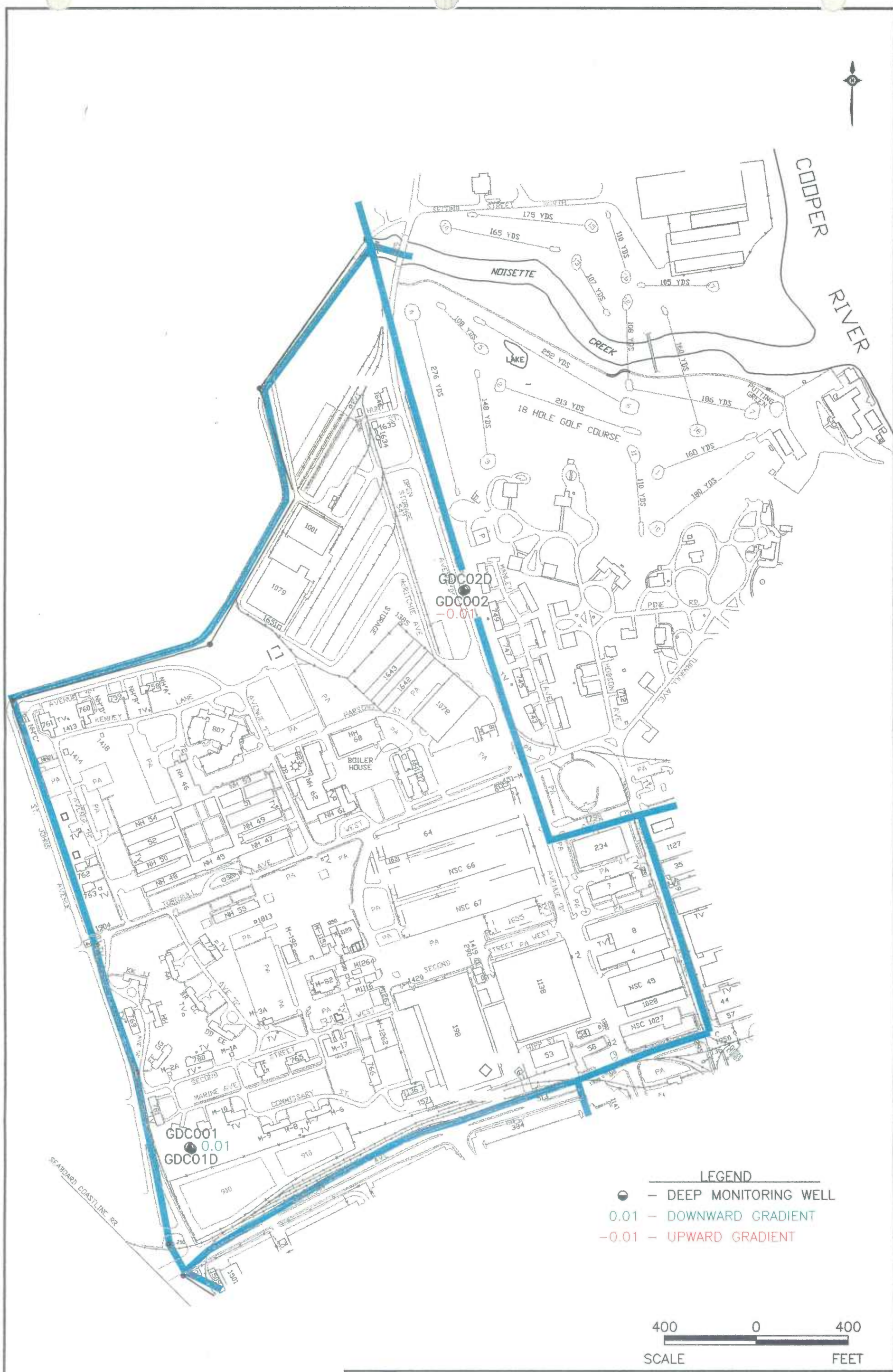
**Table 2.2**  
**Vertical Hydraulic Gradients**

Well Pair	Groundwater Elevation Difference (ft)	Vertical Distance (ft)	Vertical Hydraulic Gradient (ft/ft)
GDC001/GDC01D	0.3	22.5	0.01
GDC002/GDC02D	-0.8	59	(-)0.01

*Note:*

(-) = upward potential

The well pair at GDC001/GDC01D has a downward hydraulic gradient (positive), indicating the potential for groundwater to flow from upper to lower portions of the aquifer. The well pair at GDC002/GDC02D exhibits a negative vertical gradient, indicating a potential for upward vertical flow of groundwater in the aquifer. This is probably a reflection of the presence of a Qc aquitard overlying the deep well screen and the fact that the well location coincides with an erosional scour in the Ashley Formation. A vertical hydraulic gradient map is provided in Figure 2.5.



ZONE C  
RCRA FACILITY  
INVESTIGATION REPORT  
NAVAL BASE CHARLESTON  
CHARLESTON, S.C.

FIGURE 2.5  
ZONE C  
VERTICAL HYDRAULIC GRADIENTS  
DWG DATE: 10/10/97 DWG NAME: 2903VHGD

000716062

### 2.2.7 Horizontal Hydraulic Gradient

The shallow groundwater elevation map (Figure 2.4) was used to construct representative groundwater flowpaths across various portions of Zone C. Six flowpaths, labeled A-F in Figure 2.4, were drawn for gradient calculations. Flowpaths A and C provide gradient estimates across SWMUs 44 and 47, respectively. The remaining flowpaths estimate generalized gradients across the zone. At some locations, well locations coincided with flowpath endpoints, while at others, estimates from the contour lines were used. Table 2.3 presents horizontal hydraulic gradients computed along each flowpath.

**Table 2.3**  
**Horizontal Hydraulic Gradient**

Flowpath	$\Delta h$ (ft)	$\Delta x$ (ft)	$i$ (ft/ft)
A	1.11	310	0.0036
B	2.41	435	0.0055
C	2.05	785	0.0026
D (shallowest)	0.74	1035	0.0007
E (steepest)	10	1050	0.0095
F	4	790	0.0051

**Notes:**

$\Delta h$  = Change in hydraulic head  
 $\Delta x$  = Change in distance  
 $i$  = horizontal hydraulic gradient

The steepest gradient was calculated in the southwestern portion of Zone C. The shallowest was in the southeastern portion of the zone. The gradients across SWMUs 44 and 47 are similar in magnitude.



### 2.2.8 Hydraulic Conductivity ( $K_h$ )

Rising and falling head slug tests were conducted to determine the hydraulic conductivity of the aquifers. The hydraulic conductivities for shallow and deep aquifer depths are presented in Tables 2.4 and 2.5 and were plotted next to their respective wells to produce Figure 2.6. Injecting the slug produced falling head data and withdrawing the slug produced rising heads. Both rising and falling head slug tests were conducted on 30% of the wells installed in Zone C.

**Table 2.4**  
**Zone C**  
**Shallow-Well Slug Test Hydraulic Conductivity Results in feet/day**

Well	Rising Head $K_h$	Falling Head $K_h$	Geometric Mean*
044001	2.75	2.86	2.80
044006	1.22	1.50	1.35
047001	14.2	8.05	10.7
047003	5.18	Not Used	5.18
047006	5.67	2.90	4.06
510001	9.57	8.81	9.18
523001	5.40	2.89	3.95
GDC001	0.830	0.530	0.660
GDC002	6.78	3.45	4.84

**Note:**

\* = Average calculated using the falling and rising head values.

**Table 2.5**  
**Zone C**  
**Deep-Well Slug Test Hydraulic Conductivity Results in feet/day**

Well	Rising Head $K_h$	Falling Head $K_h$	Geometric Mean*
GDC01D	3.02	3.85	3.41
GDC02D	0.92	0.99	0.96

**Note:**

\* = Average calculated using the falling and rising head values.



NOTE: RESULTS ARE IN FEET/DAY



ZONE C  
RCRA FACILITY  
INVESTIGATION REPORT  
NAVAL BASE CHARLESTON  
CHARLESTON, S.C.

FIGURE 2.6  
ZONE C  
HYDRAULIC CONDUCTIVITY  
GEOMETRIC MEANS  
DWG DATE: 09/30/97 DWG NAME: 29ZNCMW2

00071607Z

Data from the slug tests were compiled using the computer program AQTESOLV (Aquifer Test Solver) by Geraghty and Miller Modeling Group (1989). Rising and falling head slug test data from the aquifer were plotted using an unconfined aquifer solution. For this solution, elapsed time versus displacement (change in water levels) was plotted on a semi-logarithmic graph. Hydraulic conductivity ( $K_h$ ) was computed by the program using an equation developed by Bouwer and Rice (1976) for unconfined aquifers. The output from the program is included in Appendix C.

Because hydraulic conductivity data are lognormally distributed, the geometric mean is the best measure of central tendency. Therefore, the average hydraulic conductivity for each well is presented as the geometric mean of the falling and rising head values.

The range of shallow  $K_h$  values is 0.660 to 10.7 feet/day. The  $K_h$  value at GDE001 is anomalously low given its extensive sand development. Values at 044001 and 044006 are low due to the highly interbedded nature of sand and clay deposits associated with the marsh environment near Noisette Creek. Apart from SWMU 44, sand development within most of Zone C is extensive and fairly homogenous. An effective conductivity value ( $K_{eff}$ ) of 4.38 feet/day was calculated as the geometric mean for all shallow well locations, except those at SWMU 44. A  $K_{eff}$  value for the two SWMU 44 locations was similarly calculated as 1.94 feet/day. These values will be used in Section 2.2.9 for horizontal groundwater velocity calculations.

The geometric mean from the deep well data is 1.81 feet/day.

### **2.2.9 Horizontal Groundwater Velocity**

To estimate the rate at which groundwater and possibly dissolved contaminants are migrating, groundwater velocity was calculated using the following formula:



$$V = \frac{K * i}{n_e}$$

Where:

$V$  = horizontal groundwater velocity  
 $K$  = hydraulic conductivity  
 $i$  = horizontal hydraulic gradient  
 $n_e$  = effective porosity

The average porosity of 34.5% found in Quaternary sand (Qs) was used as the effective porosity in the equation. The horizontal hydraulic gradients presented in Section 2.2.7 and effective hydraulic conductivities ( $K_{eff}$ ) determined in Section 2.2.8 were used in the above equation.

Table 2.6 presents estimated groundwater velocity along the six flowpaths previously presented in Figure 2.4. No velocity estimates were made for the deep aquifer since only two deep wells are in Zone C.

**Table 2.6**  
**Groundwater Velocity Results**

Flowpath	$K_{eff}$ (ft/day)	$i$ (ft/ft)	Velocity (ft/day)
A	1.94	0.0036	0.0202
B	4.38	0.0055	0.0698
C	4.38	0.0026	0.0330
D	4.38	0.0007	0.0089
E	4.38	0.0095	0.1206
F	4.38	0.0051	0.0647

Notes:

$K_{eff}$  = effective hydraulic conductivity  
 $i$  = horizontal hydraulic gradient



## 2.3 Climate

The climate of the Charleston Harbor area is relatively mild compared to areas farther inland. The mountains in the northern portion of the state serve as a barrier to cold air masses from the northwest, and the Bermuda high-pressure system limits the progress of cold fronts into the area. These conditions produce relatively mild, temperate winters. Summers are hot and humid, but relatively moderate with regard to temperature extremes. Moderate summer temperatures are largely due to the influence of the Gulf Stream (S.C. SEA Grant Consortium, 1992).

The average monthly air temperatures for the Charleston area are presented in Table 2.7. The temperatures are generally moderated by marine influences and are often 2°C to 3°C lower in the summer and 3°C to 8°C higher in the winter than areas farther inland. Temperatures higher than 38°C and lower than -6.5°C are unusual for the area (S.C. SEA Grant Consortium, 1992).

**Table 2.7**  
**Mean Temperature and Wind Data**  
**for Charleston Harbor between 1970 and 1985<sup>a</sup>**

Month	Daily Max (°C)	Daily Min (°C)	Mean Speed (km/hr)	Prevailing Direction
January	16.4	3.1	14.8	SW
February	16.8	4.5	16.6	NNE
March	20.0	7.3	16.7	SSW
April	24.9	11.5	16.1	SSW
May	28.8	16.6	14.3	S
June	31.6	20.6	13.7	S
July	31.6	22.2	13.0	SW
August	31.5	21.4	12.1	SW
September	29.2	18.8	13.0	NNE
October	25.1	12.7	13.2	NNE
November	19.9	6.6	13.2	N
December	16.1	3.5	14.0	NNE
Annual	24.3	12.4	14.2	NNE

*Note:*

<sup>a</sup> = S.C. SEA Grant Consortium, 1992

The wind direction and velocity in the Charleston area are highly variable, and rather evenly distributed in all directions. The inland portions of the region are subjected to a southwest-northeast wind regime. The prevailing winds are northerly in the fall and winter, and southerly in spring and summer. The monthly average wind velocities and directions for the area range from a low of 12.1 kilometers per hour (kph) in May to a high of 16.7 kph in March. The average monthly wind speeds and prevailing wind directions are also presented in Table 2.7 (S.C. SEA Grant Consortium, 1992).

The Charleston area averages 124.9 centimeters (cm) of precipitation annually, almost exclusively rainfall. Very little precipitation is recorded as snow, sleet, or hail. The greatest mean monthly precipitation is normally received in July while the smallest amount normally occurs in November (S.C. SEA Grant Consortium, 1992).

Relative humidity in the Charleston Harbor area is normally very high and fluctuates greatly. Generally, it is higher during the summer months than other times of the year, and the coastal areas exhibit a lower relative humidity than inland areas. The monthly mean relative humidity for four different times of day are presented in Table 2.8 (S.C. SEA Grant Consortium, 1992).

Cloud cover varies widely for Charleston, with annual averages of 101 clear days, 115 partly cloudy days, and 149 cloudy days. The mean monthly clear, partly cloudy, and cloudy days for the area are also presented in Table 2.8 (S.C. SEA Grant Consortium, 1992).

**Table 2.8**  
**Monthly and Annual Mean Precipitation, Relative Humidity, and Cloud Cover**  
**for Charleston Harbor between 1960 and 1985<sup>a</sup>**

Month	Precipitation (cm)	Relative Humidity by Time (%)				Cloud Cover % Number of Days		
		0100	0700	1300	1900	Clear	Partly Cloudy	Cloudy
January	6.45	82	84	55	73	8	8	15
February	8.36	79	82	52	68	9	6	13
March	9.98	81	83	50	67	9	9	13
April	7.32	84	84	50	67	11	8	11
May	9.17	88	84	54	72	8	12	11
June	12.65	90	86	59	75	6	12	12
July	19.58	91	88	64	79	4	13	14
August	16.79	92	91	63	80	5	14	12
September	14.81	91	91	63	82	7	11	12
October	7.21	88	89	56	80	12	8	11
November	5.31	85	87	51	77	13	6	11
December	7.24	82	84	54	74	9	8	14
Annual	124.87	86	86	56	75	101	115	149

*Note:*

<sup>a</sup> = (S.C. SEA Grant Consortium, 1992)

The primary concern as far as climate extremes are concerned is the occurrence of tropical cyclones or hurricanes. Hurricanes frequent the east coast of the United States and almost always have some effect on the weather around Charleston Harbor. Hurricanes normally occur between August and December. The last hurricane to make landfall in the Charleston area was Hurricane Hugo, a class IV hurricane which struck Charleston in September 1989 causing severe damage. Tornadoes are extremely rare in the vicinity but have occurred in the inland portions of Charleston County (S.C. SEA Grant Consortium, 1992).

### 3.0 FIELD INVESTIGATION

The following section lists the objectives of the field investigation and describes the technical sampling methodologies, procedures, and protocols implemented during data collection within Zone C. Fieldwork was conducted in accordance with the *Final Comprehensive Sampling and Analysis Plan* (E/A&H, August 1994) (CSAP) and the USEPA Region IV Environmental Services Division, *Standard Operating Procedures and Quality Assurance Manual* (USEPA, February 1991) (ESDSOPQAM). Sampling and investigatory methods used in the Zone C RFI investigation are summarized in this section. Any deviations from the approved work plans, such as the number of samples collected, modified locations, or procedures, etc., were documented in the field and are discussed in detail in Section 10, Site-Specific Evaluations.

#### 3.1 Investigation Objectives

The sampling strategy for each AOC and SWMU in Zone C, as detailed in the *Final Zone C RFI Work Plan* (E/A&H, November 1995), was designed to collect sufficient environmental media data to accomplish the following:

- Characterize the facilities in Zone C.
- Define contaminant pathways and potential receptors (on and offsite, where applicable).
- Define the nature and extent of contamination, if any, at Zone C sites.
- Assess human health and ecological risk.
- Assess the need for corrective measures.

#### 3.2 Sampling Procedures, Protocols, and Analyses

##### 3.2.1 Sample Identification

All samples collected during this investigation were identified using the 10-character scheme from Section 11.4 of the CSAP. This scheme identifies the samples by site, sample matrix, location, and sample depth. The first three characters identify the site where the sample was collected. The



fourth character identifies the matrix or quality control (QC) code for the sample. The fifth through eighth characters identify the sample location. The ninth and tenth characters identify the soil sample depth or sample interval. For example: sample ID 044SB00402 is a second-interval soil sample from Boring B004 at SWMU 044. For the groundwater samples, the ninth and tenth characters identify the sampling sequence. For example, 523GW00101 is the first groundwater sample collected from monitoring well W001 at AOC 523, and 523GW00102 would indicate the second groundwater sample collected.

### **3.2.2 Soil Sampling**

Section 4 of the CSAP describes soil sampling procedures and activities used in the RFI. The following subsections summarize site-specific procedures implemented in Zone C.

#### **3.2.2.1 Soil Sample Locations**

Soil samples were collected from locations proposed in the *Final Zone C RFI Work Plan* (E/A&H, November 1995), which were based on the investigation strategy outlined in Section 1.2 of that document. Each SWMU and AOC primary sampling pattern is justified in Sections 2.1 through 2.6 of the Work Plan. Some proposed sample locations were modified slightly due to utility locations. A few locations were inaccessible due to the thickness of concrete overlying the soil.

At some sites, additional samples were required to adequately characterize contaminant distribution. After the analytical data were interpreted for samples collected during the initial round of soil sampling, a second sampling round was proposed in some areas to define the extent of contamination. Typically, additional sample locations were justified due to relatively high contaminant concentrations identified on the previous sampling pattern's perimeter.

#### **3.2.2.2 Soil Sample Collection**

Composite soil samples were generally collected for laboratory analysis from 0 to 1 foot bgs and from 3 to 5 feet bgs. The 0- to 1-foot bgs interval is referred to in this report as the first or upper interval sample. At soil sample locations overlain by pavement, the upper interval was collected from the base of the pavement to 1 foot below the base of the pavement. The 3- to 5-foot bgs interval is referred to as the second or lower interval sample. No other intervals were sampled due to the relatively shallow depth to groundwater in Zone C, typically from 2 to 6 feet bgs. No saturated soil samples were retained for laboratory analysis.

Stainless-steel hand augers were used to collect soil samples. At sodded locations, the sod (generally less than 2 inches thick) overlying the soil sample at the upper interval was removed before augering to 1 foot bgs. As the auger filled with soil, it was removed from the hole, and its contents were placed in stainless-steel mixing bowls. This process was repeated until the entire interval had been collected. The lower interval sample was collected using a clean decontaminated stainless-steel auger, following the same procedures. A coring machine was used at numerous locations to gain access to soil covered by concrete and/or asphalt.

#### **3.2.2.3 Soil Sample Preparation, Packaging, and Shipment**

Section 11 of the CSAP details procedures for sample preparation, packaging, and shipment. Below is a brief overview of the procedures for soil samples.

Sample material was transferred from the stainless-steel bowl to a glass sample jar using a stainless-steel spoon. Samples collected for volatile organic analysis (VOA) were not homogenized, but were containerized immediately with zero headspace to minimize the possibility of volatilization. Soil for all other analyses was homogenized with a stainless-steel spoon and packed into appropriate containers. Any remaining soil was returned to the auger hole. Bentonite pellets, hydrated in place, were used to fill any remaining space.

Soil samples were identified as described in Section 3.2.1 of this document, and in accordance with Section 11.4 of the CSAP. From the moment of collection, labels were affixed to each sample container. Other pertinent information such as weather conditions, date and time of collection, sampling team, and a sketch of the location was included in a Zone C soil sampling logbook.

Soil sample containers were individually custody-sealed, encased in protective bubble wrap and a resealable plastic bag, and placed in a cooler for shipment. The samples were further packed with ice and double-bagged in waterproof resealable plastic bags to ensure proper preservation at 4°C. All samples were then entered onto an official chain-of-custody form, which was then affixed to the top, inside surface of the sample cooler.

After entering sample numbers, analyses, times, date, and an air-bill shipping number into an official shipping log, the coolers were shipped priority overnight via FedEx to the analytical laboratories.

#### **3.2.2.4 Soil Sample Analysis**

Soil samples were analyzed per USEPA SW-846 methods at Data Quality Objective (DQO) Level III unless otherwise noted, as follows:

•	Volatile organic compounds (VOCs)	USEPA Method 8240	18
•	Semivolatile organic compounds (SVOCs)	USEPA Method 8270	19
•	Pesticides/polychlorinated biphenyls (PCBs)	USEPA Method 8080	20
•	Cyanide	USEPA Method 9010	21
•	Metals	Title 40 Code of Federal Regulations (CFR) Part 264 Appendix IX	22 23
•	Total petroleum hydrocarbons (TPH)	USEPA Method 418.1	24

Approximately 10% of the soil samples collected in Zone C were duplicated and submitted for Appendix IX analytical parameters at DQO Level IV. These additional samples were collected to fulfill quality assurance/quality control (QA/QC) standards while cost-effectively analyzing additional parameters.

In addition to the analyses listed above, the following Appendix IX parameters were also analyzed for:

•	Hexavalent chromium	USEPA Method 218.4	
•	Dioxins	USEPA Method 8290	
•	Herbicides	USEPA Method 8150	
•	Organophosphate pesticides	USEPA Method 8140	

If contaminants were detected above risk-based screening levels, additional samples were collected for soil engineering parameter data to be used in the CMS and the contaminant fate and transport assessment of this report.

The engineering parameters were as follows:

•	Cation Exchange Capacity (CEC)	USEPA Methods 9080, 9081	
•	Total Organic Carbon (TOC)	USEPA Method 9060	
•	pH	USEPA Method 9045	
•	Nitrate	USEPA Method 9056	
•	Nitrite	USEPA Method 9056	
•	Ammonia	USEPA Method 350	
•	Phosphorus (total)	USEPA Method 365.4	
•	Sulfur (percent)	ASTM* D-129-64	



• Chlorides (percent)	ASTM D-2015-77	1
• Bulk Density	ASTM D-1587-83	2
• Soil Moisture	ASTM D-2216-80	3
• Unsaturated Hydraulic Conductivity	ASTM D-2434-68	4
• Grain-Size Analysis	ASTM D-422-63	5
• Hydrometer Analysis	ASTM D-422	6
• Synthetic Precipitation Leachate Procedure	USEPA Method 1312	7
• Porosity	Sowers and Sowers, 1951	8

*Note:* \* American Society for Testing and Materials 9

### 3.2.3 Monitoring Well Installation and Development 10

Section 5 of the CSAP describes the methods used during monitoring well installation and 11  
development. All monitoring wells were installed in accordance with South Carolina Well 12  
Standards and Regulations after permits were acquired from the South Carolina Department of 13  
Health and Environmental Control (SCDHEC). The following subsections briefly describe the 14  
site-specific methods applied in Zone C. Appendix A includes all lithologic boring logs and 15  
monitoring well construction diagrams for Zone C. 16

#### 3.2.3.1 Shallow Monitoring Well Installation 17

The shallow monitoring wells were installed so that groundwater samples could be collected from 18  
the shallow aquifer's upper portion. These monitoring wells were installed using the hollow-stem 19  
auger drilling method, which involved augering to the total depth of the borehole using hollow- 20  
stem auger flights tipped with a lead auger head. The total depth of the shallow wells depended 21  
primarily on depth to groundwater. Every effort was made to bracket the water table surface at 22  
each shallow monitoring well location. However, this was not always possible due to the shallow 23  
depth to groundwater. Because groundwater is encountered at approximately 2 to 6 feet bgs across 24  
NAVBASE, the typical depth shallow monitoring well was 11 to 13 feet bgs. 25

For each monitoring well borehole, a 2-foot split-spoon was collected for lithologic characterization at 5-foot intervals. These soil samples were visually classified and screened for organic vapors by the onsite geologist, but were not retained for chemical analysis. Typical split-spoon sample intervals in shallow monitoring well boreholes were collected between 3 to 5 feet bgs, 8 to 10 feet bgs, and 13 to 15 feet bgs. A sample representing the lithology of the typical screened interval for each SWMU/AOC was retained for grain-size analysis from one well boring at each site.

Typical shallow monitoring well construction involved placing a 10-foot section of 2-inch inside diameter (ID) polyvinyl chloride (PVC) screen with 0.010-inch slots attached to 10 feet of 2-inch ID PVC riser pipe down the inside of the hollow-stem auger, after having drilled to the desired depth. Filter pack material was then poured into the annular space between the hollow-stem auger and PVC to approximately 2 feet above the top of the screened section. As the sand was added, the level in the annulus borehole was measured with a weighted tape. The hollow-stem auger sections were gradually withdrawn while the sand was added to allow uniform placement of the filter pack and to avoid bridging and inadvertently raising the well screen and riser casing with the augers. Care was taken to never raise the hollow-stem auger sections higher than the filter pack level in the borehole, preventing the formation from collapsing on the well screen. Bentonite pellets were placed from the top of the filter pack to ground surface and hydrated with potable water. After allowing the bentonite to hydrate, for approximately 24 hours, the surface mount was constructed. An expansion locking well cap provided temporary groundwater protection before the surface mount was completed.

### **3.2.3.2 Deep Monitoring Well Installation**

Review of regional geology identified the Ashley Formation of the Cooper Group as the shallowest formation most capable of retarding or preventing downward flow of water and/or contaminants. This formation is widely noted in the Charleston area for its low permeability and its effectiveness

as a confining layer over the underlying Santee Limestone. Deep monitoring wells were installed to allow groundwater sampling at the shallow aquifer's base in contact with the underlying Ashley Formation.

Rotosonic drilling methods were used to install the deep monitoring wells. Rotosonic drilling combines standard rotary action with sonic vibration. The sonic vibration created at the surface is directed to the subsurface through the drill string, displacing formation material rather than forcing cuttings back to the surface as do more traditional drilling methods. The Rotosonic method produces a continuous core sample that allows for extremely accurate lithologic characterization. Soil samples were logged and classified as described in Section 3.2.1. Ten- to 20-foot core sections were typically produced, depending on anticipated proximity to the target formation.

Upon identification of the target depth, monitoring wells were constructed much as they were through hollow-stem augers. A 10-foot section of 2-inch ID, 0.010-inch factory slot PVC screen was installed with the base of the screen at the contact between the Ashley Formation and the overlying Pleistocene sediments. Attached to the screen was an appropriate length of 2-inch ID PVC riser pipe. Filter pack sand was placed to approximately 2 feet above the screened interval and settled by activating the sonic vibration. A bentonite seal at least 3 feet thick was placed on top of the filter pack, settled with vibratory action, and then hydrated. The remaining interval of borehole was then tremied to the surface with a high solids bentonite grout.

### **3.2.3.3 Monitoring Well Protector Construction**

The well protectors installed were either the flush-mount, manhole type, or above-grade protective casing type, depending on the well location. Well protectors were installed in accordance with Section 5.4 of the CSAP.



Flush-mount well protectors were installed in vehicle traffic areas such as parking lots. 1  
Above-grade steel protective casings were installed at all other areas. In the case of flush mounts, 2  
a 2-foot by 2-foot section of material, typically concrete or asphalt, was removed from around the 3  
borehole to approximately 6 inches deep. An 8-inch ID, by 8-inch deep flush-mount cover with 4  
a bolt-down access cover was then placed over the capped well. The top of the completed well 5  
cover was generally 2 inches above adjacent surfaces. Concrete was added to fill the 2-foot by 6  
2-foot excavated area and mounded to provide a sloped surface away from the cover. A monitoring 7  
well identification tag listing the well number, date installed, drilling subcontractor, total well 8  
depth, and depth to groundwater was mounted onto the sloped concrete surface of each flush- 9  
mount pad. Expansion caps and keyed-alike locks were placed on each monitoring well with a 10  
flush-mount cover. 11

Above-grade well protectors were prepared by installing a 3.5-foot long, 4-inch by 4-inch section 12  
of steel protective surface casing approximately 1 to 1.5 feet down over the PVC riser pipe. Care 13  
was taken not to compromise the integrity of the bentonite seal overlying the filter pack material. 14  
The protective casings were hinged approximately 6 inches from the top to allow access to the top 15  
of the PVC riser pipe. The hinged covers for each above-grade protective casing were designed 16  
to allow for security locking. A 4-foot by 4-foot concrete pad approximately 6 to 8 inches thick 17  
was then constructed around each protective casing. Weep holes were drilled through the well 18  
protector at a height that would not allow water to rise above the top of the well. A 3-inch 19  
diameter bumper post was set at each corner of the pad. A monitoring well identification tag 20  
listing the well number, date installed, drilling subcontractor, total well depth, and depth to 21  
groundwater was mounted onto the hinged cover of each above-grade well protector pad. Each 22  
hinged cover was secured with a keyed-alike lock. 23

### **3.2.3.4 Monitoring Well Development**

Monitoring well development consisted of initially stressing the filter pack by surging and pumping until turbidity was reduced as much as practical and specific conductance, pH, and temperature stabilized. Wells were developed according to Section 5.5 of the CSAP.

#### **Surging Procedures:**

1. Decontaminated PVC rods were attached to a surge block.
2. The surge block was lowered into the monitoring well screen section.
3. The surge block was then raised and lowered so groundwater would be surged in and out of the monitoring well screen.
4. Surging was conducted for approximately 10 to 15 minutes per well.
5. The surge block was removed from the well for decontamination.

#### **Shallow Well Pumping Procedures:**

1. Decontaminated polyethylene tubing was lowered into the well.
2. The tubing was attached to a centrifugal pump at the surface and pumping was begun.
3. If the productivity of the monitoring well was low, it would be alternately pumped then left idle to recover.
4. Monitoring wells were developed until the water column was as free of turbidity as possible, given the subsurface conditions and until the pH, temperature, and specific conductance were stabilized to satisfy the following criteria:

---

Temperature:	within $\pm 1.0^{\circ}\text{C}$	1
pH:	within $\pm 0.5$ standard unit	2
Conductivity:	within $\pm 10\%$ from the duplicate	3
Turbidity:	generally between 10 and 30 nephelometric turbidity units (NTUs)	4
	or relatively stable ( $\pm 15$ NTU)	5

At least three well volumes of groundwater were removed from each well during development. 6

### 3.2.4 Groundwater Sampling 7

Groundwater was sampled in accordance with Section 6 of the CSAP. The following subsections 8  
 briefly summarize the site-specific methods applied in Zone C. 9

#### 3.2.4.1 Groundwater Sampling Locations 10

Groundwater samples were collected from well locations based on the approved locations 11  
 identified in the *Final Zone C RFI Work Plan* (E/A&H, November 1995). Some proposed 12  
 locations were adjusted for access and to avoid utilities. 13

Additional samples were required at some sites to adequately characterize contaminant 14  
 distribution. After analytical data were interpreted for samples collected during the initial soil 15  
 sampling rounds, a second round of samples was collected in some areas. Typically, additional 16  
 sample locations were justified due to relatively high concentrations of contaminants on the 17  
 perimeter of the previous sampling pattern. 18

#### 3.2.4.2 Groundwater Sample Collection 19

Groundwater sample collection followed these steps: 20

1. Wells were allowed to recover for at least two weeks after being developed. 21

2. Decontaminated sampling equipment and supplies were transported to the monitoring well. 1  
2
3. A temporary work area was established around each well by placing plastic sheeting on the sampling table and around the well. Personal protective equipment (PPE) was 3  
4  
5  
6  
donned in accordance with the approved health and safety plan (HASP) for the monitoring well to be sampled. 6
4. The condition and security of the monitoring well were recorded in the field logbook. 7  
The security casing was unlocked and the well cap removed. Headspace was 8  
immediately measured for VOCs using an organic vapor analyzer (OVA), which was 9  
also used to monitor the breathing zone before and during sampling. 10
5. Depth to water and total depth of the well were measured using an oil-water interface 11  
probe if OVA readings exceeding background, odor, or other indicators suggested a 12  
light nonaqueous phase liquid (LNAPL) on the water surface. A water-level meter was 13  
used if no LNAPL was suspected. All measurements were recorded to the nearest 14  
1/100th of a foot. Static water-level measurements were taken from the top of casing 15  
at a permanent datum point notched in the well casing. Well volumes were calculated 16  
and all measurements and observations recorded in the field logbook. All equipment 17  
was decontaminated before reuse. 18
6. New decontaminated Tygon tubing was installed in the well. The tubing extended into 19  
the well and, if water level was sufficient, positioned above the screened interval. A 20  
peristaltic pump was positioned at the surface, and the tubing mounted through the 21  
pump. Groundwater was purged into graduated buckets or containers to take volume 22  
measurements, which were recorded in the field logbook. 23



7. Each well was purged of at least three well casing volumes of water. Temperature, pH, specific conductance, and turbidity were measured after each volume of water was removed from the well casing. A well was considered stabilized for sampling once temperature, specific conductance, and pH readings varied less than 10% or less between the last two readings. Turbidity was monitored until the reading was less than 10 NTUs or turbidity was lowered as much as practical and no more than five well casing volumes of water were removed. Wells that were purged dry due to slow recovery were sampled after 12 hours of recovery. Purging of some wells to achieve turbidity of less than 10 NTUs was not possible due to lithologic variabilities. For example, wells installed in areas with increased silt content were typically more difficult to achieve a turbidity of less than 10 NTUs.
8. After purging, groundwater samples were collected according to the analytical parameters proposed for each groundwater sample. Sample containers for pesticide, herbicide, metals, sulfate, sulfide, sulfite, carbonate, bicarbonate, chloride, phosphate, and SVOC analyses were collected from the discharge side of the Tygon tubing. VOC analyses samples were obtained by capping the tubing and raising it from the well and then allowing the contents of the tube to drain into the sample containers.

Groundwater sample locations were identified according to Section 3.2.1 of this report and Section 11.4 of the CSAP.

#### **3.2.4.3 Groundwater Sample Preparation, Packaging, and Shipment**

Guidelines in Section 11 of the CSAP were followed for the preparation, packaging, and shipment of groundwater samples collected during the Zone C RFI. The following briefly summarizes those activities.

Groundwater samples were preserved according to laboratory criteria for parameters being collected. Appropriate labels and custody seals were completed and affixed to each sample bottle. Glass sample containers were encased with bubble wrap and enclosed in a resealable plastic bag to protect against breakage during shipment. Plastic sample containers were also placed in a resealable plastic bag prior to shipment. Immediately after sample collection and identification, sample containers were placed on ice in coolers. Records of sampling were entered into a dedicated field logbook and a master logbook placed in a fireproof safe in the site trailer.

Groundwater sample containers were individually custody-sealed, encased in protective bubble wrap and a resealable plastic bag, and placed in a cooler for shipment. The samples were then packed with ice and double-bagged in waterproof resealable plastic bags to ensure proper preservation at 4°C. All sample information was recorded on an official chain-of-custody form, which was then affixed to the top, inside surface of the sample cooler. Temperature blanks were included with each shipment to monitor sample temperature upon arrival. All samples were recorded into a chain-of-custody form affixed to the inside of the top of each cooler.

After entering sample numbers, analyses, times, and an air-bill shipping number into an official shipping log, the coolers were shipped priority overnight to the analytical laboratories.

#### **3.2.4.4 Groundwater Sample Analysis**

Groundwater samples were analyzed per USEPA SW-846 methods at DQO Level III unless otherwise noted, as follows:

- |   |                 |                   |    |
|---|-----------------|-------------------|----|
| • | VOCs            | USEPA Method 8240 | 20 |
| • | SVOCs           | USEPA Method 8270 | 21 |
| • | Pesticides/PCBs | USEPA Method 8080 | 22 |
| • | Cyanide         | USEPA Method 9010 | 23 |

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•	Metals	40 CFR Part 264 Appendix IX	1
•	TPH	USEPA Method 418.1	2

Approximately 10% of the groundwater samples collected at Zone C were duplicated and submitted for Appendix IX analytical parameters at DQO Level IV. These additional samples were collected to fulfill QA/QC standards while cost-effectively analyzing sites for additional parameters.

In addition to the analyses listed above, Appendix IX parameters include:

•	Hexavalent chromium	USEPA Method 218.4	8
•	Dioxins	USEPA Method 8290	9
•	Herbicides	USEPA Method 8150	10
•	Organophosphorous pesticides	USEPA Method 8140	11

Groundwater samples collected from several grid-based monitoring wells in Zone C were analyzed for engineering parameters relevant to the CMS. These parameters included:

•	Temperature	Measured during sample collection	15
•	pH	Measured during sample collection	16
•	Biochemical Oxygen Demand (BOD)	USEPA Method 405.1	17
•	Chemical Oxygen Demand (COD)	USEPA Methods 410.1, 410.2, or 410.3	18
•	Alkalinity	USEPA Method 310.2	19
•	Hardness	USEPA Method 130.2	20
•	Total Suspended Solids (TSS)	USEPA Method 160.2	21
•	Total Dissolved Solids (TDS)	USEPA Method 160.1	22
•	Total Organic Carbon (TOC)	USEPA Method 415.1	23

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• Nitrate	USEPA Method 352.1	1
• Nitrite	USEPA Method 354.1	2
• Ammonia	USEPA Method 350.1	3
• Phosphorus (Total)	USEPA Method 365.1	4

The zone-wide second round of quarterly groundwater sampling was conducted in September 1995. Second-round sampling results are not included in this report.

### 3.2.5 Sediment and Surface Water Sampling

Sediment and surface water were sampled in accordance with Section 7 of the CSAP. The following subsections briefly summarize those methods as applied in Zone C.

#### 3.2.5.1 Sediment and Surface Water Sample Locations

Sediment and surface water samples were collected from the approved locations identified in the *Final Zone C RFI Work Plan* (E/A&H, November 1995). All sediment and surface water sample locations were accessible by solid land, except those collected in Noisette Creek, for which a boat was used. Surface water samples were collected before any sediment samples to prevent increasing the turbidity in the water samples.

#### 3.2.5.2 Sediment and Surface Water Sample Collection

Composite sediment samples were collected for laboratory analysis from 0 to 6 inches bgs using the scoop sampling method outlined in Section 7.2.3 of the CSAP. Surface water samples were collected in accordance with Section 7.3 of the CSAP.

Stainless-steel spoons and bowls were used to collect sediment samples. Upon identification of the sample location, a decontaminated stainless-steel spoon or spatula was used to expose a previously unexposed surface. Using a clean decontaminated stainless-steel spoon, the exposed



sediment was then scooped into a decontaminated stainless-steel bowl. For VOC samples, the sample containers were filled directly from the sampling device while filtering out twigs, large rocks, and grass. The rest was homogenized in the bowl and placed into the appropriate sample containers.

Surface water samples were collected by submerging the appropriate sample containers with the open end pointed upstream. Care was taken not to disturb bottom sediments during the sampling procedure. VOC samples were collected first.

#### **3.2.5.3 Sediment and Surface Water Sample Preparation, Packaging, and Shipment**

Guidelines in Section 11 of the CSAP were followed for the preparation, packaging, and shipment of sediment and surface water samples collected during the Zone C RFI. The following briefly summarizes those activities.

Sediment and surface water samples were identified at the time of collection in accordance with Section 11.4 of the CSAP and as stated in Section 3.2.1. Samples were stored on ice in a cooler until prepared for shipment. Date and time of sample collection, weather, sampling team, sketch map of sample location, tidal phase, and analytical parameters were recorded in the Zone C sampling logbook for individual or groups of samples.

At the close of each day of sampling, sediment and surface water samples were grouped by sample identification, individually custody-sealed and encased in bubble wrap, double-bagged in waterproof plastic bags, and placed in a sample cooler. Ice, double-bagged in waterproof, resealable plastic bags, was placed on top of the samples to preserve them at approximately 4°C. Prior to sealing the sample cooler for shipment, all sample data were entered onto an official chain-of-custody form which was then affixed to the top, inside surface of the sample cooler. The coolers were then secured and two custody seals were affixed prior to shipment.

Records of sampling were entered into a dedicated field logbook and a master logbook placed in a fireproof safe in the site trailer. Sample coolers were shipped by air for next-day delivery to the analytical laboratories.

#### **3.2.5.4 Sediment and Surface Water Sample Analysis**

Sediment samples were analyzed per USEPA SW-846 at DQO Level III unless otherwise noted, as follows:

- |   |         |                             |
|---|---------|-----------------------------|
| • | TOC     | USEPA Methods 415.1, 415.2  |
| • | Cyanide | USEPA Method 9010           |
| • | Metals  | 40 CFR Part 264 Appendix IX |

Approximately 10% of the sediment samples collected in Zone C were duplicated and analyzed at DQO Level IV.

Surface water samples were analyzed using the following methods:

- |   |                 |                                                                           |
|---|-----------------|---------------------------------------------------------------------------|
| • | VOC             | USEPA Method 8240                                                         |
| • | SVOC            | USEPA Method 8270                                                         |
| • | Pesticides/PCBs | USEPA Method 8080                                                         |
| • | Cyanide         | USEPA Method 9010                                                         |
| • | Metals          | 40 CFR Part 264 Appendix IX                                               |
| • | Organotins      | Per Triangle Laboratories, Research Triangle Park,<br>North Carolina SOP* |

**Note:** \* Standard Operating Procedures



Approximately 10% of the surface water samples collected in Zone C were duplicated and analyzed at DQO Level IV.

### **3.2.6 Wipe Sampling**

Wipe sampling was conducted in accordance with Section 9 of the CSAP. The following subsections briefly summarize those methods as applied in Zone C.

#### **3.2.6.1 Wipe Sampling Locations**

The sample locations were not based on any predetermined locations, but were collected from interior walls and ceilings in areas most likely to have been impacted (i.e., areas with air movement patterns, ledges, or vents). The wipes were supplied by the analytical laboratory in a pre-cleaned glass jar. A new pair of disposable gloves was worn to collect each individual wipe sample.

#### **3.2.6.2 Wipe Sample Collection**

Lead wipe samples were collected by swabbing or wiping the material or surface with No. 42 Whatman Filters that were dampened with deionized water. The wipes were supplied by the Wisconsin Occupational Health Laboratory of Madison, Wisconsin, in 8-ounce, pre-cleaned glass jars. The wipe filters were removed from the sample jar using tweezers or gloves. A clean set of gloves was used with each individual sample to prevent cross-contamination. The sample area was 6 inches square. To ensure a consistent sampling area, a 6-inch square template was used. The entire sampling area was wiped with firm strokes using only one side of the filter. The filter was folded with the exposed sides against each other, then folded again. The filter was then returned to the sample jar from which it was taken. Care was taken to tightly reseal the jar to prevent solvent evaporation. The area sampled in square inches was noted in the field logbook. One filter blank was dampened with deionized water, folded, and returned to the sample jar to serve as a media blank.

### **3.2.6.3 Wipe Sample Preparation, Packaging, and Shipment**

The sample jar was labeled immediately in accordance with Section 11.4 of the CSAP. The jars were individually custody-sealed, encased in bubble wrap, and boxed for shipment. A chain-of-custody form was prepared and placed in the box. The samples were shipped overnight to WOHL. Air-bill information and sample labels were kept in a master sample log.

### **3.2.6.4 Wipe Sample Analysis**

Wipe samples were analyzed for:

- Bulk lead Per laboratory SOP

One wipe sample was collected as a duplicate to fulfill QA/QC requirements.

### **3.2.7 Vertical and Horizontal Surveying**

Monitoring well locations and elevations were determined by conventional plane surveying techniques. The horizontal and vertical control were established from existing monumentation on NAVBASE with horizontal datum of NAD 83 (North American Datum, 1983) and vertical datum of NGVD 29 (National Geodetic Vertical Datum, 1929). All traverse closures exceeded 1/20,000. No data corrections were required as part of the monitoring well survey. Soil boring and monitoring well locations were surveyed using Global Positioning System (GPS).

### **3.2.8 Aquifer Characterization**

Rising and falling head slug tests were conducted on nine shallow and two deep monitoring wells to enhance aquifer characteristic estimates. Before a slug test was initiated, the static water level in each well was measured using an electronic water-level indicator. A slug was then introduced into the well, at which time the water level and the time " $T_0$ " were recorded. Periodically, water level/elapsed-time measurements were recorded as the head returned to the original level.

Similarly, each rising head slug test was preformed by removing the slug and recording water level/elapsed-time measurements as the head returned to normal. The time required for a slug test to be completed and the water level rate of change are functions of the hydraulic conductivity of the aquifer.

The slug consisted of 5-foot, and 6-foot, 1.5-inch diameter solid Teflon cylinders with stainless-steel eyebolts attached at one end. A nylon rope tethered to the eyebolt suspended the slug in the well just above or below the water level. At the beginning of each test, the data logger was activated the instant the slug was either lowered into or removed from the water.

For each slug test, In-Situ pressure transducers and 2-channel Hermit 1000C data loggers were used to record water level/elapsed-time measurements. To facilitate graphing the data, the data loggers were programmed to measure and record water level on a logarithmic time scale. Raw data from the data loggers were downloaded to a personal computer for data reduction and manipulation.

### **3.2.9 Decontamination Procedures**

Decontamination procedures were performed in accordance with Section 15 of the CSAP and Appendix B, Section B-8 of the ESDSOPQAM for sampling equipment and in accordance with Appendix E, Section E-9 of the ESDSOPQAM for drilling equipment, with the following exceptions. The detergent used on this project was Liquinox, which contains powerful chelating agents to bind and remove trace metals from sampling equipment. When available, hot water was used for field decontamination. PVC well construction materials were not solvent-rinsed or washed with hot water. Field reagent-grade water was produced onsite to meet the specifications of ASTM Type III water (D 1193-77 re-approved 1983, federal test method 7916). The steam cleaner and/or high-pressure hot water washer was capable of generating adequate pressure and producing hot water and/or steam. All wastes generated during decontamination were

containerized in designated drums for disposal by the Navy in accordance with Section 16 of the CSAP.

#### **3.2.9.1 Decontamination Area Setup**

The decontamination area is a concrete pad sloped to direct wash runoff into a catch basin, from which liquids were pumped regularly into designated containers. Equipment was cleaned on sawhorses or auger racks above the concrete surface. When field cleaning was necessary, plastic sheeting was placed on the ground to contain any spills.

#### **3.2.9.2 Cross-Contamination Prevention**

The following procedures were implemented during sampling activities to reduce cross-contamination risk.

- Fresh disposable outer gloves were donned before handling sampling equipment.
- Only Teflon, glass, or stainless-steel spray bottles/pressurized containers were used to apply decontamination rinsates. Each solution was kept in a separate container.
- All necessary decontaminated field equipment was transported to the sampling location to minimize the need for field cleaning.

#### **3.2.9.3 Nonsampling Equipment**

Nonsampling equipment includes drill rigs, and backhoes. Nonsampling equipment was decontaminated using the following procedures:

1. Equipment was decontaminated with high-pressure steam.



2. Portions of the equipment which came in contact with sampled material were scrubbed with a laboratory-grade detergent and clean water wash solution. 1  
2

3. Equipment was rinsed with clean water as necessary. 3

#### 3.2.9.4 Sampling Equipment 4

Sampling equipment includes any downhole equipment (e.g., augers, drill pipe, and split-barrel samplers) and any sampling utensils (e.g., pumps and stainless-steel spoons, spatulas, bowls), not dedicated to the sample location. Hollow downhole equipment or equipment with holes potentially transmitting water or drilling fluids were cleaned on the inside and outside. The decontamination procedure is as follows: 5  
6  
7  
8  
9

1. Protective gloves were donned before decontaminating the equipment. 10

2. Items were washed and scrubbed with a laboratory-grade detergent and clean water wash solution or sprayed with high-pressure steam. 11  
12

3. Rinsed with ASTM Type III water. 13

4. Rinsed with organic-free water. 14

5. Rinsed twice with pesticide-grade isopropyl alcohol. 15

6. Rinsed with ASTM Type III water. 16

7. Air dried. If weather prohibited air drying, the isopropyl alcohol rinse was repeated and the item was rinsed with ASTM Type III water twice. 17  
18

8. Items were wrapped in aluminum foil or plastic sheeting if the sampling equipment was stored or transported. 1  
2
9. Augers and drill rods were covered in clean plastic after decontamination. 3



## 4.0 DATA VALIDATION

### 4.1 Introduction

Data quality objectives are qualitative and quantitative statements specifying the quality of data required to support decisions during environmental response actions. The level of certainty regarding the precision of the data varies with the intended end use of the data. According to USEPA guidance, *Data Quality Objectives for Remedial Response Activities, Development Process*, EPA/540/G-87/003, March 1987, the levels of analytical data were as follows:

- Level I — Field screening or analysis using portable instruments. Results are often not compound-specific and not quantitative, but results are available in real-time. It is the least costly analytical option.
- Level II — Field analyses using more sophisticated portable analytical instruments: in some cases the instruments may be set up in a mobile laboratory onsite. There is a wide range in the quality of the data that can be generated. It depends on the use of suitable calibration standards, reference materials, and sample preparation equipment in addition to training of the operator. Results are available in real-time or in several hours.
- Level III — All analyses performed in an offsite analytical laboratory. Level III analyses may use Contract Laboratory Program (CLP) procedures, but do not usually use the validation or documentation procedures required of CLP Level IV analysis. The laboratory may not be a CLP laboratory.
- Level IV — CLP routine analytical services (RAS). All analyses are performed in an offsite analytical laboratory following CLP protocols. Level IV is characterized by rigorous Quality Assurance/Quality Control (QA/QC) protocols and documentation.

- Level V — Analysis by nonstandard methods. All analyses are performed by an offsite analytical laboratory which may not be a CLP laboratory. Method development or method modification may be required for specific constituents or detection limits. CLP special analytical services (SAS) are Level V.

For the RFI at NAVBASE Charleston, analytical Level III data with 10% analyses for Appendix IX at Level IV were deemed appropriate for the intended data uses: site characterization, risk assessment, and corrective measure determinations/design.

It should be noted that in September 1993, USEPA replaced this guidance with an updated manual, *Data Quality Objectives Process for Superfund, Interim Final Guidance*, EPA/540/G-93/071 which stated, "This guidance replaces the earlier guidance EPA 540/G-87/003, OSWER Directive 9355.0-7B and the five analytical levels introduced in that document." As a result, the five analytical data levels were reduced to two — screening data and definitive data.

Definitive data (formerly Level III and IV) are defined as analytical data generated using rigorous analytical methods, such as approved USEPA reference methods. These data are analyte-specific, with confirmation of analyte identity and concentration. These approved methods produce tangible raw data (e.g., chromatograms, spectra, digital values) in the form of paper printouts or computer-generated electronic files. Also for data to be definitive, analytical or total measurement error (precision) must be determined (EPA/540/G-93/071, September 1993). As a result, the data collected at NAVBASE Charleston are now defined as definitive data per the most recent USEPA guidance, but will still be referred to as Level III and Level IV throughout the report to avoid confusion.

## 4.2 Validation Summary

This section presents the QA/QC evaluation of the data that were produced from the analysis of environmental media samples collected within Zone C during the RFI. The purpose of this evaluation is to verify that the appropriate QA/QC elements were followed and/or completed (e.g., method requirements, documentation), to identify and/or characterize any problems with the data set, and ultimately to determine the usability of the analytical data with respect to site characterization, risk assessment, and corrective measure determinations.

Examples of definitive data (formerly Level III and IV) QA/QC elements are as follows:

- Sample documentation (verified time of sample receipt, extraction and holding times)
- Chain-of-custody
- Initial and continuing calibration
- Determination and documentation of detection limits
- Analyte(s) identification
- Analyte(s) quantification
- QC blanks (trip, method, rinsate)
- Matrix spike recoveries
- Performance Evaluation (PE) samples (when specified)
- Analytical method precision
- Total measurement error determination

As part of the RFI, environmental samples were collected at NAVBASE Charleston Zone C from February to September 1995. All samples were analyzed by CompuChem Laboratories except for the dioxin and organotin samples. Southwest Laboratory of Oklahoma, Inc. analyzed the samples for dioxins and dibenzofurans. Triangle Labs of Research Triangle Park, NC, analyzed the organotins samples. In accordance with the approved *RFI Comprehensive Sampling and*

Analysis Plan, (E/A&H, August 1994), sample analyses followed the guidance in the *USEPA Test Methods for Evaluating Solid Waste*, SW-846 and 40 CFR Part 264. The analytical methods and DQO laboratory deliverables are summarized on Table 4.1.

Table 4.1  
 NAVBASE Analytical Program

Full Scan/Appendix IX Analytical Methods	Data Quality Level	Method Reference
Volatile Organic Compounds	III/IV	SW-846 8240
Semivolatile Organic Compounds	III/IV	SW-846 8270
Pesticides/Polychlorinated Biphenyls	III/IV	SW-846 8080
Chlorinated Herbicides	III/IV	SW-846 8150
Organophosphorus Pesticides	III/IV	SW-846 8140
Total Petroleum Hydrocarbons (TPH)	III	USEPA 418.1/3550 & 5030
Metals	III/IV	40 CFR Part 264 Appendix IX (SW-846 6010/7060/7421/7471/7740/7740)
Hexavalent Chromium	III/IV	USEPA 218.4
Polychlorinated dibenzo-p-dioxins	III/IV	USEPA 8290
Organotins	III/IV	Triangle Laboratory SOP

**Notes:**

Full Scan parameters include: VOCs, SVOCs, Pest/PCBs, TPH, and Metals (Level III). Appendix IX parameters include: VOCs, SVOCs, Pest/PCBs, Herbicides, Organophosphorus Pesticides, Metals, Hexavalent Chromium and Dioxins (Level IV). Organotins were analyzed on a per-site basis.

The methods listed in Table 4.1 are from:

- USEPA Office of Solid Waste and Emergency Response (OSWER), *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods* (SW-846), Third Edition, revised July 1992.
- USEPA Environmental Monitoring and Support Laboratory, *Methods for Chemical Analysis of Water and Wastes* (EPA-600/4-79-020, revised March 1983).



- USEPA 40 Code of Federal Regulations Part 264, Appendix IX (52 Federal Register 25947, July 1987).

Third-party independent data validation of all analytical work performed under the CSAP was conducted by Validata Chemical Services based on the QC criteria, the *USEPA National Functional Guidelines for Organic and Inorganic Data Review*. The third-party validator's function was to assess and summarize the quality and reliability of the data to determine their usability and to document any factors affecting data usability such as compliance with methods, possible matrix interferences, and laboratory blank contamination.

#### 4.2.1 Organic Evaluation Criteria

The USEPA methods in *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods*, and *Methods for Chemical Analysis of Water and Wastes* define QC criteria that the laboratory must meet. However, the methods do not address data evaluation from a user's perspective. Data evaluation criteria for the user are available in *USEPA Contract Laboratory National Functional Guidelines for Organic Data Review* (Functional Guidelines), February 1994. For NAVBASE Zone C, these functional guidelines were used throughout the data evaluation process for this purpose.

Data evaluation included the following parameters:

- Holding times
- Gas Chromatography/Mass Spectroscopy (GC/MS) instrument performance checks
- Surrogate spike recoveries
- Instrument calibration
- Matrix spike and matrix spike duplicates (MS/MSD)

• Blank analysis	1
• Internal standard (IS) performance	2
• Compound quantitation	3
• Field duplicate precision	4
• Calculations	5

When the QC parameters do not fall within the specific method guidelines, the data evaluator annotated or flagged the corresponding compounds where deficiencies were found. The following validation flags were used to annotate data exhibiting laboratory and/or field deficiencies or problems:

<b>U</b>	<b>Undetected</b> — The analyte was analyzed for but not detected or was also found in an associated blank, but at a concentration less than 10 times the blank concentration for common constituents (acetone, methylene chloride) or five times the blank concentration for other constituents (benzene, toluene). The associated value shown is the quantitation or reporting limit.	10 11 12 13 14
<b>J</b>	<b>Estimated Value</b> — One or more QC parameters were outside control limits.	15
<b>UJ</b>	<b>Undetected and Estimated</b> — The analyte was analyzed for but not detected above the estimated quantitation limit. The quantitation limit is estimated because one or more QC parameters were outside control limits.	16 17 18
<b>R/UR</b>	<b>Unusable Data</b> — One or more QC parameters grossly exceeded control limits.	19



**EMPC**      **Estimated Maximum Possible Concentration** — The dioxin analyte was analyzed 1  
for, but due to possible instrument carryover that cannot be verified, results may 2  
actually be lower. 3

These validation flags were applied to data where deficiencies were noted. The EMPC validation 4  
flag used by the validator is unique to the dioxin validation reports. Appendix D includes the 5  
complete analytical dataset for Zone C. 6

#### **4.2.1.1 Holding Times** 7

Acceptable technical holding times are specified in the CSAP. The sample holding time depends 8  
on the type of analysis. For water and soil samples, the holding time for VOC analysis is 14 days 9  
from the collection date. SVOC, pesticide/PCB, organophosphorus pesticide and chlorinated 10  
herbicide water samples must be extracted within seven days from the collection date and analyzed 11  
within 40 days after extraction. For soil, samples must be extracted within 14 days of sample 12  
collection and analyzed within 40 days of collection. Dioxin water and soil samples require 13  
extraction within 30 days of collection and analysis within 45 days of collection. 14

Holding times for total petroleum hydrocarbons (TPH) analyses are 28 days from the day of 16  
collection for preserved and refrigerated samples. 17

#### **4.2.1.2 GC/MS Instrument Performance Checks** 19

Performance standards for VOC and SVOC analyses are analyzed to determine if the data 20  
produced by the instrument may be correctly interpreted according to the requirements of the 21  
method being used. Performance standards must be analyzed within 12 hours of sample analysis, 22  
and the results must be within the established criteria. 23

### 4.2.1.3 Surrogate Spike Recoveries

Surrogate compounds are added to samples and laboratory blanks before extraction and sample preparation to evaluate the effect of the sample matrix on extraction and measurement procedures. Surrogates are organic compounds chemically similar to analytes of interest but those not normally found in environmental samples. Three surrogate compounds are added to samples for VOC analysis, eight are added to samples for SVOC analysis, two are added to pesticide/PCB and dioxin samples, and one is added to both organophosphorous pesticides and chlorinated herbicide samples. Percent recovery of the surrogates is calculated by comparing the amount of the compound recovered by the analysis to the amount added to the sample.

The surrogate compounds recommended by the SW-846 methods are listed in Table 4.2. Abbreviations for each compound are in parentheses when applicable.

**Table 4.2**  
**Surrogate Compound Summary**

VOC Surrogates	SVOC Surrogates	Pesticide/PCB Surrogates	Herbicide Surrogate	Organophosphorous Pesticide Surrogate
Toluene-d8	Nitrobenzene-d5 (NBZ)	Tetrachloro-m-xylene	2,4-Dichloro-phenylacetic	4-Chloro-3-Nitrobenzotrifluoride
Bromofluorobenzene (BFB)	2-Fluorobiphenyl (FBP)	(TCMX)	acid (DCAA)	(CNBT)
1,2-Dichloroethane (DCE)	Terphenyl-d14 (TPH)	Decachlorobiphenyl (DCB)		
	2,4,6-Tribromophenol (TBP)			
	Phenol-d5 (PHL)			
	2-Chlorophenol-d4 (2CP)			
	1,2-Dichlorobenzene-d4 (DCB)			
	2-Fluorophenol (2FP)			
<b>Dioxin Surrogates</b>				
<sup>13</sup> C <sub>12</sub> - 1,2,3,4 -Tetrachlorodibenzo-p-dioxin (TCDD)				
<sup>13</sup> C <sub>17</sub> - 1,2,3,7,8,9-Hexachlorodibenzo-p-dioxin (HxCDD)				

### 4.2.1.4 Instrument Calibration

Instruments are initially and continually calibrated with standard solutions to verify that they can produce acceptable quantitative data for the compounds.

*Initial calibration (GC/MS):* The instrument is initially calibrated at the beginning of the analytical run to check its performance and to establish a linear five-point calibration curve. The initial calibration is verified by calculating the relative response factor (RRF) and the percent relative standard deviation (%RSD) for each compound. An RRF less than 0.05 or a %RSD greater than 30% is outside the QC limits for the initial calibration.

*Continuing calibration (GC/MS):* Standard solutions are run periodically to check the daily performance of the instrument and to establish the 12-hour RRF on which the sample quantitations are based. The continuing calibration is verified by calculating the RRF and the percent difference (%D) for each compound. An RRF less than 0.05 or a %D greater than 25% is outside the QC limits for the continuing calibration.

*Initial calibration (GC):* For single-component pesticides five-point calibrations are analyzed, and calibration factors (CF) are established. The CF for single-component pesticides must be less than or equal to 20%.

The multi-component pesticide toxaphene and all PCBs (or Aroclors) are analyzed separately. Retention times and CFs are determined for three to five primary peaks. The only review criteria for multi-component compounds is to verify these steps were taken.

A five-point initial calibration is analyzed for herbicides, organophosphorous pesticides, and TPH. Two methods for calibration may be used: external or linear regression methods. For the external method, the initial calibration may be verified by calculating the RRF and the %RSD for each compound. An RRF less than 0.05 or a %RSD greater than 20% is outside the QC limits for the initial calibration. If linear regression is used, the correlation coefficient must meet or exceed 0.995 before samples can be analyzed.



*Continuing calibration (GC):* The calibration verification is to confirm the calibration and evaluate instrument performance for single-component pesticides. The calibration verification consists of an instrument blank, performance evaluation mixtures (PEMs), and the midpoint concentration of the two standard mixes. The continuing calibration is run on two GC columns (a primary and a secondary) for analyte confirmation. The %D between the calculated amount and the true amount must not exceed 15% on the primary column. Multi-component compounds do not require continuing calibration.

For herbicides and organophosphorous pesticides, the continuing calibration is verified by calculating the RRF and the %D for each compound. An RRF less than 0.05% or a %D greater than 15% is outside the QC limits for the continuing calibration.

For NAVBASE Charleston, only positive results were flagged when the %RSDs and %D were outside control limits but less than 50%. If the %RSD or %D exceeded 50%, both the positive and nondetected results were flagged. Based on professional judgment, the results were flagged in this manner because the risk would be in reporting results with a high bias rather than a low bias.

#### **4.2.1.5 Matrix Spike/Matrix Spike Duplicate (MS/MSD)**

An MS is used to determine the accuracy of the analysis for a given matrix. An MS consists of a known quantity of stock solution added to the sample before its preparation and analysis. Evaluating the MS data involves two calculations. First, the percent recovery (%R) is calculated by comparing the amount of the compound recovered by the analysis to the amount added to the sample. In addition, the relative percent difference between the MS and the MSD samples is calculated and assessed. No specific requirements have been established for qualifying MS/MSD data. However, guidelines to aid in applying professional judgment are discussed in *Functional Guidelines for Organic Review*.

#### 4.2.1.6 Laboratory Control Samples and Laboratory Duplicates

Total petroleum hydrocarbons and other GC methods may require laboratory control samples (LCS) and laboratory duplicates with each Sample Delivery Group (SDG). The LCS monitors the overall performance of each step during analysis, including sample preparation. All aqueous LCS %R results must fall within the control limits established by the laboratory. Laboratory duplicate samples are used to demonstrate acceptable method precision at the time of analysis. The RPD between the sample and the duplicate sample is calculated. Although no guidelines are established for organic laboratory duplicates, sample qualification is left up to professional judgment.

#### 4.2.1.7 Blank Analysis

Laboratory method blanks are used to assess the existence and magnitude of potential contamination introduced during analysis. Additionally, field blanks may be collected to assess any contamination introduced during sample collection. When chemicals are found both in samples and laboratory blanks analyzed within the same 12-hour period and/or field-derived blanks, the usability of the data depends on the reviewer's judgment and the blank's origin. According to the functional guidelines, a sample result should not be considered positive unless the concentration of the compound in the sample exceeds 10 times the amount in any blank for common laboratory contaminants (i.e., methylene chloride, acetone, 2-butanone, and phthalate esters), or five times the amount for other constituents. These amounts are referred to as *action levels* (ALs). Because blank samples may not be prepared using the same weight of sample, volume of sample, or dilution, these factors should be also taken into consideration when using these blank criteria. The specific actions to be taken are as follows:

- If a chemical is found in the blank but not the sample, no action is taken.
- If the sample concentration is less than the quantitation limit and less than the AL, the quantitation limit is reported.

- If the sample concentration is between the quantitation limit and the AL, the concentration is reported as nondetect *U*.
- If the sample concentration is greater than the AL, the concentration may be used unqualified.

#### 4.2.1.8 Field-Derived Blanks

For this project, four types of field-derived blanks were collected: the field blank, the rinsate blank, the equipment blank, and the trip blank. The field blank is a sample of the source water used onsite, primarily to decontaminate equipment. The rinsate blank is a sample of runoff water from one or more pieces of the decontaminated equipment used to collect samples. The equipment blank is a sample of each filter pack, grout, bentonite pellets, or powder used in well construction. The trip blank is a 40-milliliter (ml) VOA vial filled with certifiable water used to assess cross-contamination during VOC sample shipment.

The frequencies for collecting these QC samples were defined in Section 13 of the *NAVBASE CSAP* as follows:

- Field blank — one per sampling event (week) per source.
- Rinsate blank — one per week per media.
- Equipment blank — one sample of each well construction material per source.
- Trip blank — one per sample shipping cooler containing VOA samples.

For data validation purposes, each trip blank is associated only with the samples from the same shipment or cooler. The field blanks and the rinsate blanks apply to a larger number of samples because only one is collected per sampling event. Because field-derived blanks are used with method blanks to assess potential cross-contamination of field investigative samples, no action was



taken if the same contaminants were detected in the method blanks and the associated field-derived blanks, but not in the investigative samples.

#### 4.2.1.9 Internal Standard Performance

GC/MS internal standards (IS) are added to samples to check the stability of the instrument's sensitivity and response during each analytical VOC and SVOC run. IS area counts for samples and blanks must not vary more than a factor of two (-50% to +100%) from the associated calibration standard. If IS concentration results are outside this window, the sample would be flagged as estimated. Listed below are the internal standard compounds recommended by the methods. Abbreviations for each compound are in parentheses.

##### VOC IS Compounds

Bromochloromethane (BCM)  
 1,4-Difluorobenzene (DFB)  
 Chlorobenzene-d5 (CBZ)

##### SVOC IS Compounds

1,4-Dichlorobenzene-d4 (DCB)  
 Naphthalene-d8 (NPT)  
 Acenaphthene-d10 (ANT)  
 Phenanthrene-d10 (PHN)  
 Chrysene-d12 (CRY)  
 Perylene-d12 (PRY)

##### Dioxin

<sup>13</sup>C<sub>12</sub>- 2,3,7,8-TCDD  
<sup>13</sup>C<sub>12</sub>- 2,3,7,8-TCDF  
<sup>13</sup>C<sub>12</sub>- 1,2,3,7,8-PeCDD  
<sup>13</sup>C<sub>12</sub>- 1,2,3,7,8-PeCDF  
<sup>13</sup>C<sub>12</sub>- 1,2,3,6,7,8-HxCDD  
<sup>13</sup>C<sub>12</sub>-1,2,3,4,7,8-HxCDF  
<sup>13</sup>C<sub>12</sub>-1,2,3,4,6,7,8-HpCDD  
<sup>13</sup>C<sub>12</sub>-1,2,3,4,6,7,8-HpCDF  
<sup>13</sup>C<sub>12</sub>-OCDD  
 TCDD (Tetrachlorodibenzo-p-dioxin)  
 HpCDF (Heptachlorodibenzofuran)  
 TCDF (Tetrachlorodibenzofuran)  
 OCDD (Octachlorodibenzo-p-dioxin)  
 PeCDF (Pentachlorodibenzofuran)  
 HpCDD (Heptachlorodibenzo-p-dioxin)  
 HxCDD (Hexachlorodibenzo-p-dioxin)  
 HxCDF (Hexachlorodibenzofuran)

#### 4.2.1.10 Diluted Samples

A special evaluation was performed of diluted samples to determine if method detection limits were sufficiently low to be compared with reference concentrations (e.g., Maximum Contaminant Levels, RBCs, etc.). Table 4.3 lists all diluted samples from Zone C.

#### 4.2.2 Inorganic Evaluation Criteria

The USEPA methods described in *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods*, and *40 Code of Federal Regulations Part 264, Appendix IX* define quality control criteria that the laboratory must meet, but the methods do not address data evaluation from a user's perspective. Evaluation criteria are available in *USEPA Contract Laboratory National Functional Guidelines for Inorganic Data Review*, February 1994. The guidelines were used throughout the data evaluation process to address data usability.

Data evaluation for samples collected at NAVBASE included:

- Holding times
- Instrument calibration
- MS results
- Laboratory duplicates
- Blank analysis
- Inductively Coupled Argon Plasma (ICAP) interference check samples

**Table 4.3**  
**Diluted Samples**

Sample ID	Sample Delivery Group	Parameter	Dilution Factor	Results (μg/kg)
047SB00501	00035	Fluoranthene	5	1,700
520SB00102	0005P	Chlordane	10	37 J
520SB00201	0005P	Chlordane	10	1,700 J
520SB00202	0005P	Chlordane	2	68 J
513CB00201	0010A	Famphur	0.4	9 J
047SB01601	0022S	Benzo(k)fluoranthene	2	8,700 J

- ICP serial dilutions 1
- Laboratory control sample results 2
- Atomic Absorption (AA) duplicate injections and post-digestion spike recoveries 3
- Field duplicate precision 4

According to the functional guidelines, when the QC parameters do not fall within the specific method guidelines, the data evaluator annotates or flags the corresponding compounds where deficiencies were found. The data from NAVBASE Charleston sites were evaluated using this approach. The following flags were used to annotate data exhibiting laboratory and/or field deficiencies or problems: 9

**U Undetected** — The analyte was analyzed for but not detected above the instrument detection limit (IDL) or was also found in an associated blank at a concentration less than 5 times the blank concentration. 10  
 11  
 12

**J Estimated Value** — One or more QC parameters were outside control limits. 13

**UJ**      **Undetected and Estimated** — The analyte was analyzed for but not detected above the listed estimated IDL; the IDL is estimated because one or more QC parameters were outside control limits.

**R/UR**      **Unusable Data** — One or more QC parameters grossly exceeded control limits.

#### **4.2.2.1    Holding Times**

Acceptable technical holding times are specified in the CSAP. For aqueous and soil samples, the holding time for metals analysis is six months, except for mercury, which is 28 days from the date of collection. For aqueous and soil samples, cyanide analysis has a sample holding time of 14 days from the date of collection.

#### **4.2.2.2    Instrument Calibration**

Instruments are initially and continually calibrated with standard solutions used to check that they are capable of producing acceptable qualitative and quantitative data for the analytes on the inorganics list.

An initial calibration is performed to check the performance of the instrument at the beginning of the analytical run and to establish a linear calibration curve. Calibration standard solutions are run periodically to check the performance of the instrument and confirm that the initial calibration curve is still valid. Calibrations are verified by calculating the %R and comparing the amount of the analyte recovered by analysis to the known amount of standard. The %R for metals, except mercury and cyanide, should fall between 90% and 110%. The %R for mercury and cyanide should fall between 80% and 120% and 85% and 115%, respectively.



#### 4.2.2.3 Blank Analysis

Laboratory method blanks are used to assess the existence and magnitude of potential contamination introduced during analysis. Additionally, field blanks may be collected to assess the potential contamination introduced during sample collection. When chemicals are found in samples and laboratory blanks, the usability of the data depends on the reviewer's judgment and the blank's origin. According to the functional guidelines, a sample result should not be considered positive unless the sample concentration exceeds five times the amount in any blank. These also are referred to as ALs. Because blank samples may not be prepared using the same weight of sample, volume of sample, or dilution, these variables should also be considered when using these blank criteria. The specific actions to be taken are as follows:

- If a chemical is found in the blank but not the sample, no action is taken.
- If the sample concentration is between the IDL, and less than five times the amount found in any blank, the concentration is reported as *U*.
- If the sample concentration is greater than five times the amount in any blank, the concentration may be used unqualified.

#### 4.2.2.4 ICAP Interference Check Samples

The ICAP interference check sample is used to confirm the laboratory instrument's inter-element and background correction factors. Interference samples should be analyzed at the beginning and end of each sample analysis or at least twice per eight-hour working shift. The %Rs for the interference check sample should fall between 80% and 120%.



#### 4.2.2.5 Laboratory Control Samples (LCS) 1

LCS are used to monitor the overall performance of steps in the analysis, including the sample 2  
preparation. All aqueous LCS %R results must fall within the control limits of 80% to 120%, 3  
except for antimony and silver, for which control limits have not been established. Soil LCS 4  
standards are provided by the USEPA. Control limits are established for each soil LCS standard 5  
prepared. 6

#### 4.2.2.6 Spike Sample Analysis 7

Samples are spiked with known quantities of analytes to evaluate the effect of the sample matrix 8  
on digestion and measurement procedures. The %R should be within 75% to 125%. However, 9  
when the sample concentration exceeds the spike concentration by a factor of four or more, spike 10  
recovery criteria are not applicable. 11

#### 4.2.2.7 Laboratory Duplicates 12

Laboratory duplicate samples are analyzed to evaluate data precision, a measure of the 13  
reproducibility of the analysis. The RPD between the sample and the duplicate sample is 14  
calculated. A control limit of 20% RPD should not be exceeded for analyte values greater than 15  
100 times the IDL. 16

#### 4.2.2.8 Inductively Coupled Argon Plasma Serial Dilutions 17

ICAP serial dilutions assess the presence or absence of matrix interference. One sample from each 18  
set of similar matrix type is diluted by a factor of five. For an analyte concentration that is at least 19  
a factor of 100 times above the IDL, the measured concentrations of the undiluted sample and the 20  
diluted sample should agree within 10%. 21

**4.2.2.9 Atomic Absorption (AA) Duplicate Injections and Post-Digestion Spike Recoveries**

During AA analysis, duplicate injections and post-digestion spikes are used to assess precision and accuracy of the laboratory analysis. The %RSD of duplicate injections must agree within 20%. %R of the post-digestion spike sample should fall between 85% and 115%.

**4.3 Zone C Data Validation Reports**

The Zone C data validation reports are included as Appendix E for review. These reports are the outcome of the evaluations described above and are specific to the analytical data collected from the Zone C RFI.

## 5.0 DATA EVALUATION AND BACKGROUND COMPARISON

This section describes the approach and technical methodologies employed to determine types (nature) and areal extent of all chemicals present in site samples (CPSS) in soil and groundwater at Zone C SWMUs and AOCs. Nature and extent were evaluated to determine the overall distribution of constituents detected on a micro (site-specific) as well as a macro (zone-wide) scale. In addition, these data will be used to assess base-wide conditions and the relationship of contaminants between zones across NAVBASE.

Types of compounds detected in Zone C include: VOCs, SVOCs, pesticides, PCBs, dioxins, organotins, and inorganics. To evaluate the significance of detected compounds, to determine where additional sampling (if any) should be conducted, to define the extent, and to develop investigative endpoints, organic data were compared to the USEPA Region III *Risk-Based Concentration Table*, June 1996 (RBCs) and inorganic data were compared to background concentrations. The comparison pertains only to the protection of human health and does not address protection of ecological receptors. Risk to the ecosystem from the contaminants onsite is assessed in Section 8.

The site-specific nature and extent evaluations for each SWMU and AOC within Zone C are detailed in Section 10, Site-Specific Evaluations of this report.

### 5.1 Organic Compound Analytical Results Evaluation

Organic compounds detected in Zone C soil and groundwater were compared to RBCs. The RBCs listed in the site-specific evaluations in Section 10 are taken from the *USEPA Region III Risk-Based Concentration Table* (USEPA Region III, June 1996). Information such as the frequency of detection and the range of detections were also compiled (see Section 10).

Dioxin data reflect a summary of the tetrachlorodibenzo-p-dioxin (TCDD) equivalency quotient (TEQ) values as computed using the procedure identified in *Interim Procedures for Estimating*

*Risks Associated with Exposures to Mixtures of Chlorinated dibenzo-p-dioxins and dibenzofurans* (CDDs and CDFs) (USEPA, 1989), and the USEPA *Interim Supplemental Guidance to RAGS: Region IV Bulletins, Human Health Risk Assessment*, Bulletin No. 2, November 1995. For screening purposes, dioxin data were compared to the dioxin TEQ of 1.0  $\mu\text{g/kg}$  based on a peer-reviewed scientific paper (Kimbrough et al., 1984). This dioxin concentration was used as the cleanup level at the Times Beach Superfund Site.

In accordance with recent carcinogenic polynuclear aromatic hydrocarbons (cPAH) guidance, USEPA *Interim Supplemental Guidance to RAGS: Region IV Bulletins, Human Health Risk Assessment*, Bulletin No. 2, November 1995, benzo(a)pyrene equivalents (BEQs) were computed, where appropriate by multiplying the reported concentration of each cPAH by its corresponding toxicity equivalency factor (TEF). The BEQ values were then summed for each sample, and the total was compared to the benzo(a)pyrene RBC value during the screening process. The comparisons listed above pertain only to the protection of human health and do not address protection of ecological receptors. Risk to the ecosystem from the contaminants onsite is assessed in Section 8.

## 5.2 Inorganic Analytical Results Evaluation

Sample results for inorganics are more difficult to compare because inorganics are naturally occurring and ubiquitous in soil. Further compounding this difficulty is the fact that NAVBASE is predominantly dredge-fill material that has been artificially placed onsite. Background values for surface soil, subsurface soil, shallow groundwater and deep groundwater were calculated in accordance with established procedures for NAVBASE. The dataset for surface and subsurface soil consisted of 45 and 30 samples, respectively. The dataset for shallow and deep groundwater consisted of four sampling rounds from two monitoring wells at each depth. The background data were presented and approved by the project team in May 1997. The background values are presented in Table 5-1.



Table 5.1  
 Zone C Inorganic Background Reference Values for Soil and Groundwater

Inorganic	Surface soil [mg/kg] (n = 45)	Subsurface soil [mg/kg] (n = 30)	Shallow Groundwater [µg/L] (n = 8)	Deep Groundwater [µg/L] (n = 8)
Aluminum	9,990 P	23,700 P	410 M	22.2 M
Antimony	0.55 N	0.92 N	ND	ND
Arsenic	14.2 P	14.1 N	6.07 M	ND
Barium	77.2 P	68.5 P	16.7 M	52.2 M
Beryllium	X	0.98 N	0.33 M	0.32 M
Cadmium	0.65 N	0.28 N	ND	ND
Chromium	26.4 P	12.5* P	1.99 M	ND
Cobalt	3.22 P	7.1 N	1.33 M	ND
Copper	34.7 P	42.2 P	1.90 M	ND
Lead	330 P	73.2 P	3.27 M	ND
Manganese	92.5 P	106 P	608 M	147 M
Mercury	0.24 N	0.30 N	ND	ND
Nickel	12.3 P	16.7 P	3.59 M	ND
Selenium	1.44 P	2.90 N	ND	ND
Silver	X	ND	1.26 M	ND
Thallium	ND	X	ND	ND
Tin	2.95 P	2.37 P	ND	ND
Vanadium	23.4 P	56.9 N	1.96 M	0.54 M
Zinc	159 P	243 P	13.2 M	ND
Cyanide	ND	ND	ND	ND

**Note:**  
 P = Parametric UTL  
 N = Nonparametric UTL  
 M = Twice the mean  
 X = No UTL calculated (NDs > 90%)  
 ND = Not detected  
 \* = Reference value for non-clay samples  
 mg/kg = milligrams per kilogram  
 µg/L = micrograms per liter



Many compounds, particularly carcinogenic metals such as arsenic and beryllium, are typically detected at much higher concentrations than their risk-based screening levels. It is usually necessary to supplement site-specific sampling efforts with an attempt to determine the non-site-related concentrations of these compounds. The problem is to determine these reference (or background) concentrations, and how much higher than this level a parameter must be at a site before it is of concern. USEPA Region IV guidance on this subject recommends the use of twice the mean level of the background samples as an upper bound and recommends considering any site-related sample higher than its upper bound to be contaminated. Although this method is appropriate with small datasets, it would be inappropriate to use with the large grid-based soil datasets developed at Zone C. E/A&H used a dual-testing procedure to compare AOC/SWMU inorganic parameters with this grid-based dataset. A combination of a parametric or nonparametric upper tolerance limit (UTL) or reference concentration and a Wilcoxon rank sum test was used.

#### **5.2.1 Grid-Based Background Datasets**

The background datasets for Zone C soil collected from the upper and lower intervals come from 45 sample locations labeled GDC (GDCSB001 to GDCSB045). Lower interval soil samples were not collected at many of the locations because of a shallow water table. The background datasets for shallow groundwater come from two sample locations labeled GDC001 and GDC002; background datasets for deep groundwater come from sample locations GDC01D and GDC02D. The available data values for each chemical were assembled into datasets for soil and for groundwater.

Descriptive statistics were obtained for the original data values, including frequency distribution histograms and normal probability plots. Results were examined and, where appropriate (i.e., histogram positively skewed, normal probability plot concave upward, high skewness, and

kurtosis), data were transformed into natural logarithms (LN) or square roots of their original values to provide a closer approximation to a normal distribution. Descriptive statistics of the transformed data were compared to those of the originals. All of the soil datasets for inorganics required transformation before parametric analysis. No transformation was needed on the much smaller groundwater datasets, since statistical analysis was not performed.

It has been suggested that lognormal data indicate the presence of contamination in the samples at the high end of the range. However, "EPA's experience with environmental concentration data ... suggests that a Lognormal distribution is generally more appropriate as a default statistical model than the Normal distribution, a conclusion shared by researchers at the United States Geological Survey" (USEPA, 1992b, p.2).

Most of the background datasets examined were more nearly lognormal than normal. It is more reasonable to assume that lognormal background distributions of chemical concentrations are the norm for the NAVBASE than to assume that the datasets document a background that is contaminated in comparable fashion by numerous chemicals at different depths in both soil and groundwater. Nevertheless, a few potential data outliers did appear at the high end of some of the datasets, and it was important to eliminate them to preserve the integrity and utility of the background data. Normally, outliers should be removed from a dataset only in unusual circumstances and with specific reasons for each removal. In lognormal or square-root distributions, even apparently extreme values may fit a straight line on a normal probability plot of transformed data. Statistical rules of thumb for outlier removal generally are based on the variance of the sample, and include methods such as the "rule of the huge error" (Taylor, 1990, p.88), in which all values greater than four standard deviations above the mean are discarded along with Rosner's test, Dixon's test, the Shapiro-Wilk test, and others (Gibbons, 1994, pp.246-257).

Because of concerns about inadvertently including contaminated samples in the background datasets, outliers were eliminated more readily than many standard statistical guidelines would suggest. After consultation with the project team, outliers were removed on a chemical-by-chemical basis, descriptive statistics were recalculated for each chemical's dataset, and the resulting modified datasets were used for all further comparisons with background. Outliers removed from the background dataset are listed below:

*Upper interval soil*

Antimony	GDCSB00501	1.4 mg/kg
Arsenic	GDCSB00201	39.4 mg/kg
	GDCSB02801	22.4 mg/kg
	GDCSB03101	22.3 mg/kg
Barium	GDCSB04001	193 mg/kg
Lead	GDCSB01501	588 mg/kg
Manganese	GDCSB04101	101 mg/kg
Mercury	GDCSB03601	0.75 mg/kg
Nickel	GDCSB00601	27.7 mg/kg
Tin	GDCSB00101	8.1 mg/kg
Zinc	GDCSB02901	414 mg/kg
	GDCSB04001	779 mg/kg

*Lower interval soil*

Arsenic	GDCSB03002	31.6 mg/kg
Manganese	GDCSB00402	502 mg/kg
	GDCSB01002	520 mg/kg
Mercury	GDCSB01002	8.5 mg/kg

*Shallow groundwater*

Arsenic	GDCGW00204	15U $\mu\text{g/L}$ (nondetect)
Cobalt	GDCGW00103	5.2U $\mu\text{g/L}$ (nondetect)
	GDCGW00104	5.2U $\mu\text{g/L}$ (nondetect)
	GDCGW00203	5.2U $\mu\text{g/L}$ (nondetect)
	GDCGW00204	5.2U $\mu\text{g/L}$ (nondetect)
	GDCGW00104	4.75U $\mu\text{g/L}$ (nondetect)
Copper	GDCGW00104	4.75U $\mu\text{g/L}$ (nondetect)
Lead	GDCGW00101	9.1U $\mu\text{g/L}$ (nondetect)
Nickel	GDCGW00203	11.6U $\mu\text{g/L}$ (nondetect)

*Deep groundwater*

Aluminum	GDCGW01D01	54.3U $\mu\text{g/L}$ (nondetect)
Vanadium	GDCGW01D03	3.4U $\mu\text{g/L}$ (nondetect)
	GDCGW02D03	3.4U $\mu\text{g/L}$ (nondetect)



### 5.2.2 Nondetect Data

Following guidelines presented in various USEPA documents, one-half of the sample quantitation limit (SQL) was used to represent nondetect values. In practice, this meant using one-half of the *U* values reported by the analytical laboratory and confirmed by the validator. This differs from the method used to represent nondetect values for organic parameters, where the minimum of one-half the lowest *J* value or one-half the lowest *U* value is used.

### 5.2.3 Developing Datasets for Sites

Results of laboratory analyses of soil and groundwater samples from the AOCs and SWMUs were assembled into datasets for each chemical of interest from the upper interval soil and shallow groundwater, for comparison with background.

### 5.2.4 Comparing Site Values to Background

The comparison of site to background can best be understood within the context of statistical hypothesis testing. A hypothesis test involves the creation of two hypotheses, a *null* and an *alternative* hypothesis. "In the context of background contamination at hazardous waste sites, the null hypothesis can be expressed as 'there is no difference between contaminant concentrations in background areas and onsite,' and the alternative hypothesis can be expressed as 'concentrations are higher onsite'" (USEPA RAGS, 1989a, p.4-8). Under the assumption that there is no contamination, the likelihood of any observed difference between site and background can be calculated. If the probability of the observed difference is smaller than some predetermined level, a decision is made that since the observed site samples are not likely to be from the same population as the background samples, the site is considered contaminated for a particular chemical.

Two possible errors can be made in this situation. The first is that a site will be considered contaminated when in fact it is clean, which is called a false positive. The probability of this

error,  $\alpha$ , is controlled by specifying the level at which the null hypothesis is considered unlikely. The other possible error, the false-negative rate,  $\beta$ , can be seen as the probability of concluding from a test that no difference exists when in reality such a difference does exist; the site will be considered clean when in fact it is contaminated. The "power" of the test ( $1-\beta$ ), which is the complement of the false-negative rate, is a measure of the strength of the conclusion that a difference does exist; it can be thought of as the probability of correctly identifying a contaminated site (Table 5.2). The calculation of  $\beta$  and power is somewhat more difficult and depends upon the magnitude of the actual concentration differences, the size of the sample, and the form of the probability distribution for the measurement process.

**Table 5.2**  
**Probability of Possible Conclusions of a Hypothesis Test**

Test	Reality	
	Same as Background (clean)	Greater than Background (contaminated)
Same as Background	$1-\alpha$	$\beta$
Greater than Background	$\alpha$	$1-\beta$

There is a trade-off, in general, between the false-positive and false-negative rate, given a certain sample size. A test that rarely rejects the hypothesis of "no contamination" will be more prone to miss an actual difference. A test that frequently concludes contamination is present, on the other hand, will be more likely to make the mistake of concluding that a difference arising by chance is a real difference. The total amount of error can be minimized in two ways: by increasing the sample size or by using a test that is "most powerful." The choice of the form of the hypothesis test is crucial to minimizing the total error.



USEPA Region IV often suggests a "two-times background" test: If the maximum detected concentration of a chemical at a site exceeds twice the mean background level, the chemical should be considered a chemical of potential concern (COPC) and should be subjected to detailed risk analysis (i.e., the chemical is a contaminant at the site). What is often not recognized is that this procedure is a statistical one and is subject to the same errors as a hypothesis test. The problem with this approach is that background levels are never level; that is, the nature of the background data greatly affects the result of applying the "two-times background" criterion. For a normally distributed variable with a coefficient of variation (CV) of 0.25, less than 0.01% of the population is expected to be greater than twice the mean; if the CV is 1.00, 15.9% of the population is expected to exceed the standard. In the latter case, 15.9% of the presumably uncontaminated background population would be rated contaminated by the test (false positive rate = 15.9%). The "two-times background" test neglects the valuable information about variation that is present in the background samples and, therefore, cannot be the most statistically powerful test since it does not make the most effective use of the available data.

Hypothesis tests should be suited to the type of decision that needs to be made, as well as to the type of data available. Any method for comparing site to background must be capable of detecting two different kinds of site contamination. The first type involves localized "hot spots" within the site; for example, one or two site samples out of nine or 10 might test well above the highest background samples, while the rest are low or even nondetect. This situation was modeled as a mixture of two distributions — some of the samples from a given site come from a distribution similar to the background samples while others from the same site come from a second distribution with a higher mean/median. The other type of contamination occurs when most or all of the site samples are above the mean of background samples, but none is necessarily above the high end of the background range. This situation was modeled assuming that the distribution of site samples is similar to background, but with a higher mean/median. The first scenario is referred to as the mixture scenario and the second as the shift scenario. Two complementary tests were

employed for these two situations respectively — a tolerance- interval test and a Wilcoxon rank sum test.

#### **5.2.5 Tolerance-Interval or Reference Concentration Test**

Individual data values from a site can be compared to a high percentile (95th, 98th, 99th) of background values. This operation can be done parametrically by comparing to a specified percentile of the distribution of background values, obtained either from a normal probability chart of transformed values or by using standard methods of estimating quantities (e.g., Gilbert, 1987, p.175, Equation. 13.24). It can also be done nonparametrically by comparing to a percentile of the background data values themselves, rather than to an assumed distribution of the values.

Rather than comparing site values to specific percentiles of the background data, they can be compared to estimated reference concentrations that enclose a specified percentage of the background population. A one-sided tolerance interval with 95% coverage and 95% confidence signifies that approximately 95% of individual population values fall below the upper limit, with 95% confidence. Once the interval is constructed, each site sample is compared to the UTL or reference concentration (USEPA, 1992b, p.51). Any value that exceeds the limit is considered evidence of contamination at that point.

A roughly lognormal distribution of background values allows the use of parametric tolerance intervals, using LN-transformed values, when the nondetect percentage is low. Individual sample values are compared to a UTL or reference concentration that is calculated using the expression:

$$\exp[X + k (s)]$$

**where:**

X = mean of LN-transformed background values

s = standard deviation of LN-transformed values

k = tolerance factor

When a square-root data transformation is used, the comparable expression is:

$$[X + k (s)]^2$$

The tolerance factor,  $k$ , is obtained from tables with specified levels of  $\alpha$  and  $P_0$ , where  $(1 - P_0)$  equals the proportion of the population contained within the tolerance intervals. For a given set of  $\alpha$  and  $P_0$ ,  $k$  depends on the sample size,  $n$ . For  $n = 44$  (the sample size for Level 1 of background for soils),  $k = 2.0986$  when  $\alpha = 0.05$  and  $P_0 = 0.05$  (confidence = 95%, coverage = 95%). This value was generated by linearly extrapolating between tabled values of  $n = 40$ ,  $k = 2.125$  and  $n = 45$ ,  $k = 2.092$  producing the equation:

$$k = -0.0066 * n + 2.389 \text{ when } \{40 \leq n \leq 45\}$$

According to a USEPA statistical training course manual (USEPA, 1992c, p.29), "reference concentrations can be computed with as few as three data values; however, to have a passable estimate of the standard deviation, one should probably have at least eight to 10 samples." Outliers were first identified and removed from the datasets, as explained in Section 5.2.1. A UTL, or reference concentration, was then calculated for the revised dataset of each chemical in upper and lower interval soil and used for background comparisons. Shallow and deep groundwater background datasets for Zone C contain only eight samples apiece (four rounds of samples from each of two wells at each level). Reference concentrations were computed as twice the mean of each dataset.

Where a significant proportion of the soil samples were nondetect ( $> 50\%$ ), means and standard deviations could not be computed accurately, and it was necessary to employ nonparametric tolerance intervals. In these cases, the UTL or reference concentrations were taken directly from the sample sets, rather than from calculations based on the presumed data distributions. In



practice, this meant using either the largest or the second largest observed background value as the standard of comparison (USEPA, 1992b, p.54) when nondetects (ND) are greater than 50%. As with the parametric calculations, the method was applied to the datasets after removing outliers.

The following decision rule was applied to the background datasets for soil:

- Where  $ND \leq 50\%$ , use parametric UTL.
- Where  $50\% < ND < 90\%$ , use first or second highest value in dataset as the nonparametric UTL.
- Where  $ND \geq 90\%$ , no valid background value can be determined.

The power of these tolerance-limit tests varies based on several factors, such as the number of samples that are assumed to have come from the distribution with the larger mean, the magnitude of the shift in the mean, and the distribution of the background samples. It also depends upon the sample size at each site and the sample size of the background.

#### **5.2.6 Wilcoxon Rank Sum Test**

When values for the majority of a sites samples are higher than the mean background value, but none is dramatically higher, the site samples, as a group, must be shown to be significantly higher than the group of background samples for contamination to be identified at the site.

The most commonly prescribed method for comparing two populations is the *t*-test, which determines whether the two population means differ significantly. The *t*-test was not used in this report to compare site values to background because it is parametric. Although the background

data values are approximately normally distributed after being transformed (by LN or square root), there is no reason to expect that the site values will be. In addition, the presence of estimated values for the nondetects calls into question the accuracy of the calculated means that are compared within the *t*-test.

A nonparametric counterpart to the *t*-test is the Wilcoxon rank sum test, also known as the Mann-Whitney U test. Since it is nonparametric, the two datasets that are compared need not be drawn from normal or even symmetric distributions, and the test can accommodate a moderate number of nondetect values by treating them as ties (Gilbert, 1987, p.248). The method for handling nondetect and qualified values is important because it affects their ranks. Detected but not quantified values (Js) should receive higher ranks than nondetects (Us). Since the ranks of the data values are evaluated and compared rather than the values themselves, the test is not sensitive to minor inaccuracies in estimated values and does not require an estimate of the mean, nor do the data values need to be transformed. The Wilcoxon test is superior to some other nonparametric tests, such as the sign test or the test of proportions, because it takes into account differences in concentrations and, therefore, has more statistical power to detect differences in those concentrations.

The Wilcoxon rank sum test operates by combining the site and background data values and ranking them by concentration. The ranks of the site samples are then compared to the background ranks. If the site ranks, as a group, are significantly higher than those of the background, the null hypothesis that the site and background values came from the same population is rejected at a chosen confidence level (USEPA, 1992b, p.46). Each group should contain at least four data values.

The Wilcoxon test is very similar in power to the *t*-test when samples are normally distributed and it is more powerful when the distribution is skewed. The power of this test varies based on several



variables, such as the magnitude of the shift in the median, the distribution of the background samples, the sample size at each site, and the sample size of the background.

### **5.2.7 Summary of Statistical Techniques Used**

Techniques that allow the use of statistical inference were chosen. Methods must be capable of detecting situations where: (a) a small number of site values are much higher than background and (b) site values are generally higher than background. For situation (a), transform all data values where appropriate to approximate normal distributions, then compare site values to a UTL, mean plus  $k$  standard deviations, of the background data, where  $k$  depends on sample size. When the percentage of nondetects is above 50%, use nonparametric tolerance limits; above 90% nondetects, no reliable tolerance limits can be determined. For situation (b), apply the Wilcoxon rank sum test to compare each group of site values to background.

### **5.2.8 Combined results of the UTL (Reference Concentration) and the Wilcoxon Rank Sum Tests**

Methods described in Section 5.2.5 identify individual samples with concentrations that are significantly higher than background, while the method in Section 5.2.6 identifies entire sites. If the results from either test were positive (i.e., significantly higher than background), the sample and/or site values were compared to the corresponding USEPA RBCs for soils and, where appropriate, carried forward into detailed risk assessment.

### **5.2.9 Conclusion**

The overall approach documented here is conservative for a number of reasons: (1) the number of background samples (especially for soil) is above the minimum recommended in various guideline documents (USEPA RAGS, 1989a, p.4-9), producing greater confidence in the ability to characterize background and to distinguish background concentrations from those at sites; (2) following procedures described in Section 5.2.1, high values were removed from the

background datasets whether they were true outliers in the conventional sense, thereby lowering 1  
the total background levels to which the sites were compared; and (3) the use of two 2  
complementary tests increased the likelihood that any contamination would be identified and 3  
addressed further, since a positive result from either test triggered a detailed risk assessment. 4

## 6.0 FATE AND TRANSPORT

The objective of fate and transport assessments is to evaluate what is known regarding the constituents in the environment based on inherent characteristics of both the constituents and the environmental media in which they are present. Specifically, fate and transport assessment evaluates a constituent's ability to become mobile or change in the environment. To accomplish this, a general understanding of the chemical and physical properties that govern the interaction of a constituent within environmental media is required. From a macroscopic viewpoint, the characteristics of the site, such as topography, weather, geography, and geology, play a role in the transport process. From a microscopic viewpoint, the characteristics of site soil, sediment, and water, as well as the chemical and physical properties of the constituent, play a role in evaluating the processes of advection, diffusion, and dispersion that move a constituent between media or place to place within a medium. A discussion of fate and transport will help to identify potential receptors that result from the constituent movement in the environment. Site-specific conclusions regarding fate and transport are detailed in Section 10.

After evaluating Zone C, for the above characteristics, four potential routes of constituent migration have been identified:

- Air emissions resulting from VOCs released from surface soil
- The leaching of constituents from soil to groundwater
- Surface soil erosion and runoff of constituents into adjacent zones of sediment deposition
- The migration of constituents from shallow groundwater into surface water bodies

As mentioned above, significant processes of constituent migration include erosion, advection, diffusion, and dispersion and are defined as follows:

## **Erosion**

Erosion is the process by which particles are suspended and subsequently moved by the physical action of water. Compounds adsorbed to particulate material are thereby moved along with the particulates.

## **Advection**

Advection is the process by which dissolved substances migrate with flowing groundwater. Hydraulic conductivity, effective porosity, average linear velocity and hydraulic gradient are medium characteristics that determine a chemical's rate of movement by advection. This characteristic is significant for compounds associated with groundwater.

## **Diffusion**

Diffusion is the hydrodynamic process by which solutes are transported from a region of high concentration to a region of low concentration. In very fine sediments with very slow hydraulic conductivities, diffusive transport may be the dominant mode of migration.

## **Dispersion**

Dispersion is the hydrodynamic process by which solutes are mixed with uncontaminated water, diluted, and transported preferentially due to anisotropic aquifer conditions.

### **6.1 Properties Affecting Fate and Transport**

Numerous chemical and physical properties of both the constituent and the surrounding media are used to evaluate fate and transport mechanisms.

#### **6.1.1 Chemical and Physical Properties Affecting Fate and Transport**

Chemical and physical properties used to evaluate fate and transport include vapor pressure, density, solubility, half-life, Henry's law constant, organic carbon/water partitioning coefficient,



and molecular weight. Table 6.1 below provides an overview of chemical property behavior based on these properties.

**Table 6.1**  
**Chemical and Physical Properties**

Chemical Property	Critical Value	High (>)	Low (<)
Vapor Pressure (VP)	$10^{-3}$ mm Hg	volatile	nonvolatile
Density <sup>a</sup> (D)	0.75 to 1.25 g/cm <sup>3</sup>	sink/fall	float/rise
Solubility <sup>a</sup> (S)	0 to 100 mg/L	leaches from soil, mobile in water, does not readily volatilize from water	absorbs to soil, immobile in water, volatilizes from water
Henry's Law Constant (HL)	$5 \times 10^{-6}$ to $5 \times 10^{-3}$ atm-m <sup>3</sup> /mole	resistance to mass transfer in the aqueous phase	resistance to mass transfer in the gas phase
Half-life ( $T_{1/2}$ )	biologically dependent	does not degrade readily	degrades readily
Organic Carbon/Water Partitioning Coefficient <sup>a</sup> ( $K_{oc}$ )	10 to 10000 kg <sub>oc</sub> /L <sub>water</sub>	tends to adsorb to organic material in soil; immobile in the soil matrix	tends not to adsorb to organic material in soil; mobile in the soil matrix
Molecular Weight (MW)	400 g/mole	parts of the above may hold true, more detailed evaluation necessary	all of the above hold true

**Note:**

a = Determinations for the Critical Ranges were based on literature review and professional judgment.

Table 6.2 contains chemical and physical property data for each chemical detected in Zone C samples (soil, groundwater, surface water, and sediment). Section 10 discusses SWMU- or AOC-specific fate and transport, migration pathways and potential receptors.

Compounds with similar chemical and physical properties also display similar fate and transport mechanisms. This facilitates the general grouping of contaminants based on chemical and



Table 6-2

Fate and Transport Properties and Screening Levels for Constituents Detected in Soil and Groundwater

NAVBASE-Charleston, Zone C

Charleston, South Carolina

Parameter	Vapor Pressure (mm Hg)	Density (g/cm <sup>3</sup> )	Solubility (mg/L)	Henry's Law Constant (atm-m <sup>3</sup> /mole)	Organic Carbon Water Part. Coeff. (L/kg)	Salt Water Chronic WQC (ug/L)	Tap Water RBC or UTL *	Water Units	Ground Water Protection SSL or UTL **	Soil Units
Parameter	Vapor Pressure (mm Hg)	Density (g/cm <sup>3</sup> )	Solubility (mg/L)	Henry's Law Constant (atm-m <sup>3</sup> /mole)	Organic Carbon Water Part. Coeff. (L/kg)	Salt Water Chronic WQC (ug/L)	Tap Water RBC or UTL *	Water Units	Ground Water Protection SSL or UTL **	Soil Units
Acenaphthene	1.6E-03	1.024	3.47	1.70E-04	7.08E+03	NDA	220	UG/L	57000 SSL	UG/KG
Acenaphthylene	2.9E-02	0.899	3.93	2.00E-04	2.50E+03	NDA	220	UG/L	a 11000 CALC	UG/KG b
Acetone	2.7E+02	0.791	1E+06	3.97E-05	2.19E+00	NDA	370	UG/L	1600 SSL	UG/KG
Acetophenone	1	NDA	NDA	1.58E-01	3.50E+01	NDA	0.0042	UG/L	0.7 CALC	UG/KG b
Acrolein	220	0.847	200000	4.4E-06	4.90E-01	NDA	73	UG/L	290 CALC	UG/KG
Aldrin	6.0E-06	1.700	0.027	2.67E-05	4.07E+02	NDA	0.004	UG/L	500 SSL	UG/KG
Aluminum	NA	NA	NA	NA	NA	NDA	3700	UG/L	23700 REF	MG/KG c
Anthracene	2.0E-04	1.260	0.045	6.50E-05	2.60E+04	NDA	1100	UG/L	1200000 SSL	UG/KG
Antimony	NA	NA	NA	NA	NA	NDA	1.5	UG/L	5 SSL	MG/KG c
Aroclor-1254	4.1E-05	1.566	0.08	7.10E-03	4.31E+05	0.03	0.0087	UG/L	8600 CALC	UG/KG b
Aroclor-1260	4.1E-05	1.566	0.08	7.10E-03	8.22E+05	0.03	0.0087	UG/L	16000 CALC	UG/KG b
Arsenic	NA	NA	NA	NA	NA	36	6.07	UG/L	29 SSL	MG/KG c
Barium	NA	NA	NA	NA	NA	NDA	260	UG/L	1600 SSL	MG/KG c
Benzoic acid	1.0E+00	1.316	3400	7.02E-07	1.82E+02	NDA	15000	UG/L	40000 SSL	UG/KG
Benzo(g,h,i)perylene	1.0E-10	NDA	0.00026	1.40E-07	7.76E+06	NDA	150	UG/L	d 46000 CALC	UG/KG d
Benzo(a)pyrene Equivalents										
Benzo(a)anthracene	2.2E-08	1.274	0.012	2.3E-06	1.40E+06	NDA	0.092	UG/L	2000 SSL	UG/KG
Benzo(a)pyrene	5.6E-09	1.351	0.0039	2.40E-06	1.77E+06	NDA	0.0092	UG/L	8000 SSL	UG/KG
Benzo(b)fluoranthene	5E-07	NDA	0.0014	1.2E-05	5.50E+05	NDA	0.092	UG/L	5000 SSL	UG/KG
Benzo(k)fluoranthene	9.59E-11	NDA	0.00055	1.04E-03	4.37E+06	NDA	0.92	UG/L	49000 SSL	UG/KG
Chrysene	6.3E-09	1.274	0.0018	7.26E-20	9.52E+04	NDA	9.2	UG/L	160000 SSL	UG/KG
Dibenzo(a,h)anthracene	1E-10	1.282	0.005	7.33E-09	3.30E+06	NDA	0.0092	UG/L	2000 SSL	UG/KG
Indeno(1,2,3-cd)pyrene	1E-10	NDA	0.062	2.96E-20	1.60E+06	NDA	0.092	UG/L	14000 SSL	UG/KG
Beryllium	NA	NA	NA	NA	NA	NDA	0.33	UG/L	63 SSL	MG/KG
alpha-BHC	2.5E-05	1.870	1.63	5.30E-06	1.82E+03	NDA	0.011	UG/L	0.5 SSL	UG/KG
beta-BHC	2.8E-07	1.890	0.24	2.30E-07	2.48E+03	NDA	0.037	UG/L	3 SSL	UG/KG
delta-BHC	1.7E-05	1.870	0.314	2.50E-07	1.50E+03	NDA	0.037	UG/L	e 3 SSL	UG/KG e
gamma-BHC (Lindane)	6.7E-05	1.569	7.5	3.25E-06	1.21E+03	NDA	0.052	UG/L	9 SSL	UG/KG
4-Bromophenyl-phenylether	2.0E-03	1.000	NDA	1.00E-04	8.71E-04	NDA	210	UG/L	840 CALC	UG/KG b
Butylbenzylphthalate	8.6E-06	1.120	2.76	1.30E-06	1.51E+02	NDA	730	UG/L	930000 SSL	UG/KG
Cadmium	NA	NA	NA	NA	NA	9.3	1.8	UG/L	8 SSL	MG/KG
Carbon disulfide	3.0E+02	1.260	2100	1.33E-02	6.18E+01	NDA	2.1	UG/L	3200 SSL	UG/KG
Chlordane	1.0E-05	1.600	0.056	4.80E-05	4.95E+04	0.004	0.052	UG/L	10000 SSL	UG/KG
Chloroform	1.6E+02	1.489	8000	3.23E-03	4.60E+01	NDA	0.15	UG/L	600 SSL	UG/KG
Chromium	NA	NA	NA	NA	NA	50	3700	UG/L	38 SSL	MG/KG c
Chromium (hexavalent)	NA	NA	NA	NA	NA	50	18	UG/L	38 SSL	MG/KG
Cobalt	NA	NA	NA	NA	NA	NDA	220	UG/L	7.1 REF	MG/KG c
Copper	NA	NA	NA	NA	NA	2.9	150	UG/L	42.2 REF	MG/KG c
Cyanide	NA	NA	NA	NA	NA	5.2	73	UG/L	NDA	
2,4-D	1.1E-02	1.420	682	1.95E-02	5.37E+02	NDA	6.1	UG/L	1880 CALC	UG/KG b
4,4'-DDD	1.0E-06	1.476	0.02	2.16E-05	4.37E+04	NDA	0.28	UG/L	16000 SSL	UG/KG
4,4'-DDE	6.5E-06	NDA	0.04	2.34E-05	2.45E+05	NDA	0.2	UG/L	54000 SSL	UG/KG
4,4'-DDT	1.9E-07	1.560	0.005	4.89E-05	3.87E+05	0.001	0.2	UG/L	32000 SSL	UG/KG
Dibenzo(a,j)acridine	NDA	NDA	NDA	NDA	NDA	NDA	NDA		NDA	
Dibenzofuran	NDA	1.089	10	NDA	1.00E+04	NDA	15	UG/L		
Di-n-butylphthalate	1.0E-05	1.046	13	6.30E-05	1.38E+03	NDA	370	UG/L	2300000 SSL	UG/KG
Dibutyltin	NDA	NDA	NDA	NDA	NDA	NDA	0.11	UG/L	j NDA	
Dieldrin	1.8E-07	1.750	0.2	2.00E-05	1.34E+04	0.0019	0.0042	UG/L	4 SSL	UG/KG b
Diethylphthalate	2.0E-03	1.118	896	8.46E-07	6.92E+01	NDA	29000	UG/L	47000 SSL	UG/KG
Dimethoate	5.06E-06	1.281	25	2.63E-11	9.12E+00	NDA	0.73	UG/L	3.2 CALC	UG/KG b
3,3'-Dimethylbenzidine	NDA	NDA	NDA	NDA	4.47E+02	NDA	0.0073	UG/L	0.2 SSL	UG/KG

Table 6-2

Fate and Transport Properties and Screening Levels for Constituents Detected in Soil and Groundwater  
 NAVBASE-Charleston, Zone C  
 Charleston, South Carolina

Parameter	Vapor Pressure (mm Hg)	Density (g/cm <sup>3</sup> )	Solubility (mg/L)	Henry's Law Constant (atm-m <sup>3</sup> /mole)	Organic Carbon Water Part. Coeff. (L/kg)	Salt Water Chronic WQC (ug/L)	Tap Water RBC or UTL *	Ground Water Protection SSL or UTL **	Soil Units
Dinoseb	NDA	1.265	52	5.00E-04	5.01E+02	NDA	3.7 UG/L	170 CALC	UG/KG b
Di-n-octylphthalate	0.0014	0.978	3	1.41E-12	977237221	NDA	73 UG/L	1E+08 SSL	UG/KG
Dioxin (TCDD TEQ)	NDA	NDA	NDA	NDA	3.30E+06	NDA	0.5 PG/L	4 CALC	UG/KG k
Diphenylamine	NDA	1.160	insolubl	NDA	NDA	NDA	91 UG/L	NDA	
1,2-Diphenylhydrazine	NDA	1.158	NDA	NDA	9.47E+02	NDA	0.084 UG/L	3.5 CALC	UG/KG b
Disulfoton	1.8E-04	1.144	12	5.42E-06	7.76E+02	NDA	0.15 UG/L	5 CALC	UG/KG b
Endosulfan I	1.0E-05	1.745	0.53	1.01E-04	2.04E+03	0.0087	22 UG/L	1800 SSL	UG/KG
Endosulfan II	1.0E-05	1.745	0.28	1.91E-05	2.34E+03	0.0087	22 UG/L	1800 SSL	UG/KG
Endosulfan sulfate	NDA	NDA	0.117	NDA	2.34E+03	NDA	22 UG/L	1800 SSL	UG/KG f
Endrin	7.0E-07	1.650	0.23	5.00E-07	8.32E+03	0.0023	1.1 UG/L	1000 SSL	UG/KG
Endrin aldehyde	2.0E-07	NDA	0.26	3.86E-07	2.69E+04	NDA	1.1 UG/L	1000 SSL	UG/KG g
bis(2-Ethylhexyl)phthalate	2.0E-07	0.987	0.3	1.10E-05	2.00E+09	NDA	4.8 UG/L	3600000 SSL	UG/KG
Famphur	NDA	NDA	NDA	NDA	4.19E+02	NDA	22 UG/L	450 CALC	UG/KG i
Fluoranthene	5.0E-06	1.252	0.24	1.69E-02	3.80E+04	NDA	150 UG/L	430000 SSL	UG/KG
Fluorene	7.0E-04	1.203	1.69	2.10E-04	5.01E+03	NDA	150 UG/L	56000 SSL	UG/KG
Heptachlor	3.0E-04	1.660	0.18	2.30E-03	1.20E+04	0.0036	0.0023 UG/L	23000 SSL	UG/KG
Heptachlor epoxide	2.6E-06	NDA	0.35	3.20E-05	2.09E+04	0.0036	0.0012 UG/L	700 SSL	UG/KG
Lead	NA	NA	NA	NA	NA	8.5	15 UG/L	330 REF	MG/KG c
Manganese	NA	NA	NA	NA	NA	NDA	608 UG/L	106 REF	MG/KG c
Mercury	NA	NA	NA	NA	NA	0.025	2 UG/L		
Methoxychlor	1.4E-06	1.410	0.04	1.58E-05	7.94E+04	NDA	18 UG/L	160000 SSL	UG/KG
Methylene chloride	3.5E+02	1.327	20000	2.00E-03	2.30E+01	NDA	4.1 UG/L	20 SSL	UG/KG
1-Methylnaphthalene	NDA	1.006	24.6	4.11E-04	8.51E+03	NDA	150 UG/L	51000 CALC	UG/KG i
Methylnaphthalene	NDA	1.006	24.6	4.11E-04	8.51E+03	NDA	150 UG/L	51000 CALC	UG/KG i
Methylparathion	9.6E-06	NDA	50	1E-07	6.3E+01	NDA	0.91 UG/L	6 CALC	UG/KG
Monobutyltin	NDA	NDA	NDA	NDA	1.00E+06	NDA	0.11 UG/L	4400 CALC	UG/KG b
Naphthalene	5.4E-02	1.145	30	4.60E-04	9.40E+02	NDA	150 UG/L	8400 SSL	UG/KG
Nickel	NA	NA	NA	NA	NA	8.3	73 UG/L	130 SSL	MG/KG
N-Nitrosodiphenylamine	1.0E-01	1.230	0.004	NDA	1.20E+03	NDA	14 UG/L	1000 SSL	UG/KG
Parathion	9.7E-06	NDA	6.45	5.65E-07	1.00E+04	NDA	22 UG/L	8900 CALC	UG/KG
Pentachlorophenol	1.1E-04	1.978	20	2.10E-06	4.09E+02	7.9	0.56 UG/L	30 SSL	UG/KG
Phenanthrene	6.8E-04	1.179	1	3.90E-05	2.29E+04	NDA	150 UG/L	>1e+8 CALC	UG/KG d
Phenol	0.2	1.058	82000	2.7E-07	6	NDA	2200 UG/L	10000 SSL	UG/KG
Phorate	8.4E-04	1.156	20	6.40E-06	3.20E+03	NDA	0.73 UG/L	96 CALC	UG/KG b
Pyrene	2.5E-06	1.271	0.135	1.09E-05	6.46E+04	NDA	110 UG/L	420000 SSL	UG/KG
Safrole	NDA	1.096	47	NDA	661	NDA	NDA	NDA	
Selenium	NA	NA	NA	NA	NA	71	18 UG/L	5 SSL	MG/KG
Silver	NA	NA	NA	NA	NA	NDA	18 UG/L	34 SSL	MG/KG
Sulfotep	1.7E-04	1.196	25	2.88E-06	6.61E+02	NDA	1.8 UG/L	55 CALC	UG/KG
2,4,5-T	7.5E-07	1.420	278	8.68E-09	2.04E+02	NDA	37 UG/L	450 CALC	UG/KG b
2,4,5-TP (Silvex)	5.2E-06	NDA	140	1.31E-07	2.57E+03	NDA	29 UG/L	5300 CALC	UG/KG b
Thallium	NA	NA	NA	NA	NA	NDA	0.29 UG/L	0.7 SSL	MG/KG
Tin	NA	NA	NA	NA	NA	NDA	2200 UG/L	2.95 REF	MG/KG c
Toluene	2.2E+01	0.867	515	6.70E-03	1.29E+02	NDA	75 UG/L	12000 SSL	UG/KG
Total Petroleum Hydrocarbo	NDA	NDA	NDA	NDA	NDA	NDA	NDA	NDA	
Trichlorofluoromethane	6.9E+02	1.487	1100	1.10E-01	1.58E+02	NDA	130 UG/L	2300 CALC	UG/KG
Vanadium	NA	NA	NA	NA	NA	NDA	26 UG/L	600 SSL	MG/KG c
Vinyl acetate	NDA	NDA	NDA	NDA	NDA	NDA	3700 UG/L	17000 SSL	UG/KG
Zinc	NA	NA	NA	NA	NA	86	1100 UG/L	1200 SSL	MG/KG

## FOOTNOTES TO TABLE 6-2

\* - Ground water screening concentration which is the greater of:

1. Tap water risk-based concentration as presented in EPA Region III tables (June 1996)
2. Grid-based background upper tolerance limits for shallow ground water; Navbase Charleston - Zone C  
(Risk based screening concentrations assume a target risk of 1E-06 and a target hazard index of 0.1)

\*\* - Soil screening concentration selected by the following order of preference:



Table 6-2

Fate and Transport Properties and Screening Levels for Constituents Detected in Soil and Groundwater  
NAVBASE-Charleston, Zone C  
Charleston, South Carolina

Parameter	Vapor Pressure (mm Hg)	Density (g/cm <sup>3</sup> )	Solubility (mg/L)	Henry's Law Constant (atm-m <sup>3</sup> /mole)	Organic Carbon Part. Coeff. (L/kg)	Salt Water Chronic WQC ! (ug/L)	Tap Water RBC or UTL * Units	Ground Water Protection SSL or UTL **	Soil Units
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1. Groundwater protection soil screening levels as presented in USEPA Soil Screening Guidance: Technical Background Document. USEPA., EPA/540/R-95/128, May 1996; DAF = 20. Where appropriate, values were adjusted to correlate with a hazard quotient of 0.1
  2. Grid-based background upper tolerance limits - maximum of surface or subsurface soil; Navbase Charleston - Zone C
  3. Generic SSL calculated in accordance with the Soil Screening Guidance using default assumptions and USEPA MCLs as the target soil leachate concentration. The DAF was set equal to 20.
  4. Generic SSL calculated in accordance with the Soil Screening Guidance using default assumptions and tap water RBCs as the target soil leachate concentration. Tap water RBCs were selected to equate with an ILCR of 1E-6 or HQ of 0.1.
- (The USEPA SSG formula for calculating the generic groundwater protection soil SSL is provided below. )

! - Salt water chronic water quality criteria as provided in EPA (1993)

NA - Not applicable

NDA - No data available

SSL means the value was obtained from the USEPA SSG Technical Guidance Document.

REF means the value represents the background reference concentration.

CALC indicates the value was calculated in accordance with USEPA SSG methods.

a - Acenaphthene used as a surrogate

b - Calculated using Soil Screening Guidance (USEPA May 1996)

c - grid-based background upper tolerance limit

d - Fluoranthene used as a surrogate

e - gamma-BHC used as a surrogate

f - endosulfan used as a surrogate

g - endrin used as a surrogate

h - Treatment technique action level for lead

i - naphthalene used as a surrogate

j - Tributyltin oxide used as a surrogate

k - Dioxin (TCDD TEQ) soil screening value based on the tap water RBC

l - Parathion used as a surrogate

UG/L or ug/L - Micrograms per liter

UG/KG - Micrograms per kilogram

MG/KG - Milligrams per kilogram

mmHg - Millimeters of mercury

g/cm<sup>3</sup> - Grams per cubic centimeter

mg/L - Milligrams per liter

atm-m<sup>3</sup>/mole - Atmosphere cubic meters per mole

L/kg - Liters per kilogram

Generic Groundwater Protection Soil SSL formula

$$Ct = Cw * ([Koc * foc] + [(Pw + Pa * H')/d])$$

Where:

Ct	-	soil screening level (mg/kg)
Cw	-	target soil leachate concentration (mg/l)
Koc	-	organic carbon partition coefficient (L/kg) -chemical specific
foc	-	fraction organic carbon (0.002 or 2%) - conservative default
Pw	-	water filled soil porosity (0.3 unitless) - default
Pa	-	air filled soil porosity (0.13 unitless) - default
H'	-	dimensionless Henry's Law constant (H * 41) - chemical specific
d	-	soil bulk density (kg/L; 1.5) - default

physical properties into these categories: VOCs, SVOCs, pesticides/PCBs, chlorinated herbicides, chlorinated dibenzodioxins/dibenzofurans, and inorganics.

## VOCs

The chemical and physical properties with the greatest influence on the fate and transport of VOCs are solubility, Henry's law constant, and vapor pressure. Typical fate and transport characteristics are:

- VOCs can leach from soils into groundwater.
- VOCs tend to be highly mobile in both soil and groundwater.
- VOCs tend to volatilize from both soil and groundwater.
- VOCs tend to dissipate relatively quickly.

The VOCs have low molecular weights, moderate densities, and Henry's law constants, varying organic carbon/water partitioning coefficients, and high solubilities and vapor pressures. Overall, VOCs are expected to be moderately to highly mobile in the environment and to be relatively quick in attenuating from soil and groundwater.

## SVOCs

The chemical and physical properties with the greatest influence on the fate and transport of SVOCs are solubility, vapor pressure, and organic carbon/water partitioning coefficient. Typical fate and transport characteristics are:

- SVOCs tend to adsorb to soil particles.
- SVOCs tend to be immobile in the environment.
- SVOC movement tends to occur more often by colloidal suspension than by diffusion (i.e., greater mobility occurs when coupled with "carrier" compounds).

SVOCs have high molecular weights; wide-ranging vapor pressures, solubilities, and Henry's law constants; moderate to high densities; and generally high organic carbon/water partitioning coefficients. Overall, SVOCs are expected to be relatively immobile in soils and diffuse only slightly to groundwater. The most notable exception to the anticipated SVOC immobility in the environment are the phenols and substituted phenols, which have higher solubilities.

### **Pesticides/PCBs**

The chemical and physical properties with the greatest influence on the fate and transport of pesticides/PCBs are solubility, Henry's law constant, and organic carbon/water partitioning coefficient. Typical fate and transport characteristics are:

- Pesticides/PCBs tend to adsorb to soil particles.
- Pesticides/PCBs tend to be hydrophobic (avoid water).
- Pesticides/PCBs tend to be immobile in the environment.
- Pesticides/PCBs tend to degrade relatively slowly.

Pesticides/PCBs have moderate molecular weights, generally high densities and organic carbon/water partitioning coefficients, and generally low solubilities, vapor pressures, and Henry's law constants. Overall, pesticides/PCBs are anticipated to be immobile and persistent in the environment, not readily diffusing into groundwater.

### **Chlorinated Herbicides**

Solubility has the greatest influence on the fate and transport of chlorinated herbicides. Typical fate and transport characteristics are:

- Chlorinated herbicides can leach from soil particles to groundwater.
- Chlorinated herbicides tend to be mobile in both soil and groundwater.
- Chlorinated herbicides tend to degrade relatively slowly.



Chlorinated herbicides have low Henry's law constants and vapor pressures, and moderate molecular weights, organic carbon/water partitioning coefficients, and solubilities. Overall, chlorinated herbicides are expected to be moderately mobile in groundwater with some retention in soil.

### **Chlorinated Dibenzodioxins/Dibenzofurans**

The chemical and physical properties with the greatest influence on the fate and transport of chlorinated dibenzodioxins/dibenzofurans are solubility, Henry's law constant, and organic carbon/water partitioning coefficient. Typical fate and transport characteristics are:

- Chlorinated dibenzodioxins/dibenzofurans tend to adsorb to soil particles.
- Chlorinated dibenzodioxins/dibenzofurans tend to be hydrophobic (avoid water).
- Chlorinated dibenzodioxins/dibenzofurans tend to be immobile in the environment.
- Chlorinated dibenzodioxins/dibenzofurans tend to degrade relatively slowly.

Chlorinated dibenzodioxins/dibenzofurans exhibit limited mobility in most environmental settings, have a strong affinity for soil particles and organic matter, and are not expected to leach to groundwater.

### **Inorganics**

Solubility has the greatest influence on the fate and transport of inorganics. Typical fate and transport characteristics are:

- Inorganics tend to adsorb to soil particles.
- Inorganics are not degradable.
- Inorganics tend to have moderate to low mobility, however, in environments where there is a low pH (i.e., acidic conditions [pH < 5]), inorganics can become mobile.

Properties of the surrounding environmental media tend to dictate the fate and transport mechanisms of inorganic elements. Overall, inorganics are anticipated to be immobile and to remain adsorbed to soil particles, not readily diffusing into groundwater.

### 6.1.2 Media Properties Affecting Fate and Transport

The properties of environmental media used to evaluate fate and transport are TOC, normalized partition coefficient, CEC, redox conditions, pH, soil type, and retardation rate. The following briefly discusses these properties.

#### Total Organic Carbon

TOC indicates the soil's adsorptive capabilities. The higher the TOC, the higher the potential for a chemical to adsorb to soil particles.

#### Normalized Partition Coefficient ( $K_d$ )

$K_d$  is used to predict the capacity for a constituent to partition between soil and water. To estimate  $K_d$ , the constituent's organic carbon/water partitioning coefficient ( $k_{oc}$ ) is adjusted by the soil's TOC. Higher  $K_d$ s have a higher potential to adsorb organic compounds.

#### Cation Exchange Capacity

CEC reflects the soil's capacity to adsorb ions neutralizing an ionic deficiency on its surface. Generally, trivalent ions are preferentially adsorbed to soil over divalent ions, and divalent ions are preferentially adsorbed over monovalent ions. Although this is generally the case, the process also depends on soil pH. Soils with high CEC values have the potential to adsorb inorganic ions, although organic compounds with dipole moments also are affected by CEC.

## **Redox Conditions**

Redox is the process which includes oxidation (the loss of electrons), and reduction (the gain of electrons). The resultant change in oxidation state generates products that are different from the reactants in their solubilities, toxicities, reactivities, and mobilities. Primarily, redox reactions influence the mobility of inorganic chemicals. Extreme redox conditions tend to mobilize chemicals, especially inorganics.

## **pH**

The pH value is a logarithmic measure of hydrogen ions in the soil or groundwater, indicating the acidity or alkalinity of the medium. Chemicals react significantly different under changing pHs. Low pH conditions tend to mobilize chemicals, especially inorganics, while high pH conditions may lead to the formation of immobile metal hydroxides.

## **Soil Type**

The mineralogical composition, particle-size distribution, and organic content of soil influence chemical fate and transport. Soil type dictates hydraulic conductivity, effective porosity, average linear velocity, and hydraulic gradient which, in turn, affect groundwater flow.

## **Retardation Factor (R)**

The retardation factor is used to evaluate the ability for a soil or groundwater to inhibit the movement of a chemical by preferentially binding to contaminants with high organic carbon/water partitioning coefficients.

Table 6.3 summarizes the chemical and physical parameters of Zone C soil used to evaluate fate and transport. The average CEC for Zone C surface soil is 10.1 milliequivalent per liter (meq/L). Ranges for CEC were from 3.6 to 52 meq/L for surface soil. The average value for pH in Zone C soil samples (included as part of the pesticide analysis) is 6.64. The range of pH values for



Zone C soil is 4.0 to 8.3. These soil conditions indicate limited mobility for inorganics by the processes of advection, diffusion, and dispersion. The average TOC concentration for Zone C surface soil samples was 6,246 mg/kg. TOC measurements indicate a relatively high organic content that will inhibit the movement of contaminants, particularly those with high  $K_{oc}$  values, due to increased soil adsorption. The average porosity of the upper sand interval in Zone C, as determined through Shelby tube analysis, was 35%. Hydraulic conductivity for Zone C, as determined by analysis of four Shelby tube samples, is 2.07 feet/day; median hydraulic conductivity, based on slug tests in eleven wells in Zone C, is 6.71 feet/day.

**Table 6.3**  
**Soil Parameters Used to Evaluate Fate and Transport**

Parameter	Zone C Minimum Value	Upper Sand		Units
		Zone C Maximum Value	Zone C Average Value	
Cation Exchange Capacity	3.6	52	10.1	(meq/L)
Total Organic Carbon	919	22,200	6,246	(mg/kg)
pH <sup>a</sup>	4	8.3	6.64	(--)
Total Porosity	0.293	0.395	0.35	(--)
Bulk Density <sup>b</sup>	1.43	1.73	1.59	(kg/m3)

**Notes:**

- <sup>a</sup> = pH values compiled from pesticide analysis pre-screening by the laboratory  
<sup>b</sup> = Bulk density values are based on Zone C Shelby Tube data

Table 6.4 lists the approximate time of travel for groundwater flow from each AOC or SWMU to the Cooper River or Noisette Creek, depending on direction of flow, local groundwater gradient, and local hydraulic conductivity. Calculation of travel times was based on an assumption of zero elevation for water in the Cooper River and Noisette Creek. A river gauging station at the Army Depot in North Charleston at mile 10.5 of the Cooper River reported a mean river stage of

1.06 feet for the year 10/92 - 9/93. If mean river stage at Zone C is actually between zero and 1.06 feet, as indicated, then the calculations were based on a somewhat exaggerated horizontal hydraulic gradient. Consequently, results can be considered conservative.

**Table 6.4**  
**Travel Time Analysis**

AOC/SWMU	Hydraulic Conductivity (feet/day) <sup>a</sup>	Vertical/Horizontal Gradient (—)	Total Porosity (—) <sup>b</sup>	Horizontal Velocity (feet/year)	Horizontal Distance (feet) <sup>c</sup>	Travel Time (years)
SWMU 44	1.35	0.00957	0.35	13.472	230	17
SWMU 47 (Includes AOC 516)	5.18	0.00221	0.35	11.939	1,500	126
AOC 508	7.054	0.00522	0.35	38.402	2,125	55
AOC 523	3.95	0.00194	0.35	7.99	1,750	219

**Notes:**

- <sup>a</sup> = Based on slug test data from adjacent monitoring wells  
<sup>b</sup> = Total porosity is based on the average of four Shelby tube samples collected in the upper sand.  
<sup>c</sup> = Horizontal distance is based on the potentiometric path of groundwater flow.

## 6.2 Fate and Transport Approach for Zone C

Fate and transport discussion for each SWMU/AOC begins with a description of site characteristics that can affect constituent migration. As presented earlier in this section, four potential routes of constituent migration have been identified for Zone C. Each SWMU and AOC has been evaluated as to site conditions that promote these migration pathways. In some cases, it is logical to evaluate fate and transport for a combination of SWMUs/AOCs based on their proximity.

An evaluation of individual constituent's ability to migrate is based on four cross-media transfer mechanisms: soil to groundwater, groundwater to surface water, surface soil to air, and/or surface soil to sediment. Cases have been made for each of these transfer mechanisms based on empirical data available for each environmental medium sampled. For example, if a constituent is found in



surface soil as well as in groundwater, it is reasonable to conclude that surface soil constituents may be leaching to the groundwater. The chemical and physical properties of the constituent and the media were evaluated, where necessary, in support of such conclusions. Zone C fate and transport were evaluated using constituent-specific chemical and physical properties and risk-based screening concentrations or grid-based background UTLs (Table 6.2).

The following discussions describe the methods used to evaluate the potential migration of constituents identified at each SWMU/AOC. In some cases, specific migration pathways do not exist for a site. When a particular pathway was not identified for a site, no screening or formal assessment was performed. Fate and transport were not evaluated for essential nutrients (calcium, iron, magnesium, potassium, and sodium), chlorides, or sulfur, which are abundant in shallow coastal/estuarine environments.

#### 6.2.1 Soil-to-Groundwater Cross Media Transport

A phased screening approach was used to evaluate the potential for soil-to-groundwater migration of constituents, focusing attention on chemicals that have the greatest potential for impacting the shallow water-bearing zone. The screening process may be summarized as follows:

- *Qualitative* — The CPSS lists (excluding essential nutrients, chloride, and sulfur) for soil (all depths) and shallow groundwater were compared to determine which chemicals were present in both media.

Due to the nature and age of most SWMU/AOC operations, it was assumed that any impacts associated with compounds having the potential to migrate from soil would be currently manifested in the shallow aquifer. This approach is also supported by the thin, relatively permeable soil layer across Zone C. As a result, the qualitative comparison was used to identify those chemicals with reported concentrations in both media.

- *Quantitative* — Chemicals present in both media were compared to appropriate screening values. Maximum soil concentrations for each SWMU/AOC (or group thereof) were compared to the greater of leachability-based soil to groundwater screening levels, assuming a dilution attenuation factor of 10, as presented in the USEPA Region III RBC tables, June 1996 (or USEPA Soil Screening Guidance assuming a dilution attenuation factor of 10), and grid-based background UTL concentrations for soil in Zone C. Maximum groundwater analytical results for each SWMU/AOC (or group thereof) were compared to the greater of tap water RBCs and grid-based background UTL concentrations for the shallow aquifer in Zone C. For AOCs or SWMUs with available SPLP data, a quantitative comparison of SPLP concentrations (assuming a dilution attenuation of 10) to the tap water RBC was used for the quantitative assessment.

The quantitative assessment further refines the list of chemicals under consideration for formal fate and transport evaluation. It was assumed that if soil concentrations do not exceed leachability-based screening levels or background, no significant migration potential exists. Likewise, if current groundwater or SPLP concentrations do not exceed risk-based screening values, the conclusion was made that existing soil/groundwater equilibria are sufficiently protective of human health relative to potential groundwater ingestion exposure pathways.

- *Detailed Assessment* — Upon completion of the qualitative and quantitative screening processes, detailed analyses were performed to delineate the areal extent of soil impacts potentially affecting groundwater.

The outcome of the detailed assessment was used to determine the significance of soil impacts relative to the shallow aquifer. In some instances, isolated areas of soil contamination above leachability-based concentrations may have the potential for localized shallow groundwater impacts, but not of a magnitude that would pose a long-term or widespread threat to the aquifer.

The detailed assessment was used to identify these cases, as well as to make conclusions as to what areas of soil contamination may require supplemental investigation and/or modeling applications during the CMS as part of the remedial alternatives development process.

### 6.2.2 Groundwater-to-Surface Water Cross Media Transport

The principal focus of this evaluation was determining whether constituents identified in groundwater have the potential to extend their impacts or discharge to surface water. The screening process may be summarized as follows:

- *Qualitative* — The CPSS list for shallow groundwater was examined to identify the following: all constituents detected in both groundwater and surface water and all constituents that were detected in groundwater that can increase the area of impact in the shallow aquifer or to adjacent surface water bodies.

Many SWMUs/AOCs investigated at NAVBASE have no surface water onsite for a qualitative assessment. As a result, qualitative comparisons of shallow groundwater and surface water data are supported for only a few SWMUs/AOCs. Potential impact on ecological receptors was qualitative/semiquantitatively evaluated for sites with constituents detected in groundwater at concentrations above USEPAs saltwater chronic Ambient Water Quality Criteria (AWQC) protective of aquatic organisms.

- *Quantitative* — Chemicals present in groundwater and/or surface water were compared to appropriate screening values. Relative to human health evaluation, maximum shallow groundwater results for each SWMU/AOC (or group thereof) were compared to the greater of the tap water risk-based screening levels presented in the USEPA Region III RBC tables (June 1996), and grid-based background UTL concentrations for the shallow aquifer in



Zone C. Maximum surface water analytical results for each SWMU/AOC were compared to AWQC (SCDHEC and/or USEPA) to address potential ecological concerns.

The quantitative assessment identifies chemicals detected in groundwater with the potential to disperse within the aquifer, increasing the areal extent of groundwater concentrations that exceed human health-based standards, or impact surface water via groundwater migration and discharge. If groundwater concentrations do not exceed tap water risk-based screening levels and grid-based background UTLs, no significant threat relative to migration potential exists. If no constituents with published AWQC values are present in groundwater, no threat exists relative to ecological impacts resulting from groundwater discharge to surface water. This assessment does not consider potential dilution/attenuation factors affecting transport between the affected well and the surface water discharge point, or the dilution capacity of the receiving water body. Omitting these factors from the quantitative screening ensures that a conservative list of potential groundwater to surface water concerns is developed.

- *Detailed Assessment* — Upon completion of the qualitative and quantitative screening processes, detailed analyses were performed to delineate the areal extent of groundwater and/or surface water impacts that may adversely affect human or ecological receptors.

The outcome of the detailed assessments was used to determine the significance of shallow groundwater and surface water impacts. In addition, in areas where no surface water data were collected as part of the Zone C RFI, the potential for significant surface water impacts was determined preliminarily. These assessments were based on data collected from wells near surface water bodies, and in some instances, incorporated conservative estimates of the dilutional influences of the receiving stream or water body, plus travel time analysis, which assists in predicting mass flux to the receiving stream. The Zone J RFI results will be used to confirm or refute preliminary conclusions. The detailed assessment was used to identify these cases as well

as to render conclusions regarding what areas of shallow groundwater and/or surface water contamination may require supplemental investigation and/or modeling applications during the CMS as part of the remedial alternatives development process.

### 6.2.3 Soil-to-Air Cross-Media Transport

To evaluate the potential for soil to air migration of volatile contaminants, a screening approach was used to focus attention on chemicals that have the greatest potential to volatilize in sufficient quantities to create a human health threat in ambient air. The screening process may be summarized as follows:

- *Quantitative* — The maximum concentrations of volatile CPSS detected in surface soil at each SWMU/AOC were compared to soil-to-air screening concentrations as presented in the USEPA Region III RBC tables (June 1996).

The quantitative assessment further refines the list of chemicals under consideration for formal fate and transport evaluation. If soil concentrations do not exceed soil-to-air volatilization screening concentrations, no significant migration potential exists, and current soil conditions are protective of human health relative to potential inhalation exposure pathways.

- *Detailed Assessment* — After completing the quantitative screening process, detailed analyses were performed to delineate the areal extent of surface soil impacts potentially affecting ambient air.

The outcome of the detailed assessments was used to determine the significance of soil impacts relative to ambient air. In some instances, isolated areas of soil contamination above soil-to-air volatilization-based concentration may have the potential for localized ambient air impacts but not be of a magnitude to pose a long-term or widespread threat through inhalation pathways. The



detailed assessment was used to identify these cases as well as to make conclusions as to what areas of soil contamination may require supplemental investigation and/or modeling applications during the CMS as part of the remedial alternatives development process.

#### 6.2.4 Surface Soil-to-Sediment Cross-Media Transport

To evaluate surface soil to sediment erosional migration, a phased screening approach was used to identify chemicals having the potential to form contaminated sediments following surface soil erosion. The screening process may be summarized as follows:

- *Qualitative* — The CPSS lists (excluding essential nutrients, chloride and sulfur) for surface soil and sediment were compared to determine which chemicals were present in both media.

The most influential process by which sediments are formed involves the erosion of surface soil which collects in depositional areas. Site topography was used to identify areas with erosional potential and the expected area of deposition. Qualitative screening was used to identify constituents common to both media. Because erosional/depositional processes within Zone C are expected to be localized based on limited relief and soil conditions, screening focused on these localized units. Sediment results were compared to data for proximate surface soil representing the most likely point of sediment contaminant origination.

- *Semiquantitative* — Constituents present in both media, were compared to the maximum concentration in surface soil to the maximum concentration in related sediment.

The purpose of the semiquantitative assessment was to provide additional evidence in support of this migration pathway. Any impacts to ecological receptors with regard to contaminated sediments have been addressed for Zone C in Section 8 or will be addressed in the Zone J RFI dependant upon their specific location.

## 7.0 HUMAN HEALTH RISK ASSESSMENT

### 7.1 Introduction

A BRA analyzes the potential adverse effects on actual or hypothetical human and ecological receptors that could arise from exposures to hazardous substances released from a site if no remedial actions are taken to reduce the extent of present environmental contamination. Generally, a BRA is divided into two subsections; one addresses the human health risk, and the second assesses ecological risk. Data management and analysis methods used to reach the conclusions of this human health risk assessment are discussed in the following text. Ecological concerns are discussed in Section 8, Ecological Risk Assessment.

The succeeding subsections describe general methods, procedures, considerations, toxicological information, and related uncertainties affecting each SWMU- or AOC-specific BRA. Sections 7.1.1 through 7.1.8 provide a general risk assessment framework/outline to avoid presenting redundant information in subsequent site-specific assessments. As a result, the BRAs in Section 10, Site-Specific Evaluations, include only the basic mechanistic and evaluative elements applicable to evaluating risk and/or hazard at a particular SWMU or AOC.

The BRAs within Section 10 were prepared generally in accordance with the guidelines set forth in:

- *Risk Assessment Guidance for Superfund (RAGS), Volume I – Human Health Evaluation Manual (Part A)*, (USEPA, 1989a), (RAGS Part A).
- *RAGS, Volume I – Human Health Evaluation Manual (Part B, Development of Risk-Based Preliminary Remediation Goals)*, (USEPA, 1991a), (RAGS Part B).

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- *RAGS, Volume I – Human Health Evaluation Manual, Supplemental Guidance – Standard Default Exposure Factors – Interim Final*, (USEPA, 1991b), (RAGS Supplement). 1 2
  - *RAGS, Volume I – Human Health Evaluation Manual, Supplemental Guidance – Dermal Risk Assessment – Interim Guidance*, (USEPA, 1992d), (Supplemental Dermal Guidance). 3 4
  - *Supplemental Guidance to RAGS: Region IV Bulletin, Human Health Risk Assessment – Interim*, (USEPA IV, 1995a). 5 6
  - *Supplemental Guidance to RAGS: Region IV Bulletin, Development of Health-Based Preliminary Remediation Goals, Remedial Goal Options (RGO) and Remediation Levels* (Supplemental RGO Guidance), (USEPA Region IV, 1994).. 7 8 9
  - *Supplemental Guidance to RAGS: Region IV Bulletin, Provisional Guidance of Quantitative Risk Assessment of PAHs*, (USEPA Region IV, 1993), (PAH Guidance). 10 11
  - *Exposure Factors Handbook*, (USEPA, 1989d). 12
  - *USEPA Region III Risk-Based Concentration Table, January-June 1996*, (USEPA Region III, June 1996), (RBC Screening Tables). 13 14
  - *Technical Memorandum Guidance on Estimating Exposure to VOCs During Showering*, (USEPA, 1991c). 15 16

These references are identified fully in Section 12, References. 17

## 7.2 Objectives

The objectives of the BRA are to:

- Characterize the source media and determine the chemicals of potential concern (COPCs) for affected environmental media.
- Identify potential receptors and quantify potential exposures for those receptors under current and future conditions for all affected environmental media.
- Qualitatively and quantitatively evaluate the adverse effects associated with the site-specific COPCs in each medium.
- Characterize the potential baseline carcinogenic risk and noncarcinogenic hazards associated with exposure to impacted environmental media at Zone C under current and future conditions.
- Evaluate the uncertainties related to exposure predictions, toxicological data, and resultant carcinogenic risk and noncarcinogenic hazard predictions.
- Establish RGOs for chemicals of concern (COCs) in each environmental medium based on risk/hazard to facilitate risk management decision-making.

Chemical contamination at the site must be characterized adequately before risk assessment can determine whether detected concentrations have the potential for toxic effects or increased cancer incidences and before it can serve as a basis for making remedial decisions. Variables considered in characterizing the study area are the amount, type, and location of contaminant sources. Variables considered for risk characterization are the pathways of exposure (media type and



migration routes); the type, sensitivities, exposure duration, and dynamics of the exposed populations (receptors); and the toxicological properties of identified contaminants.

The focus of each SWMU and/or AOC investigation is detailed in the Site Background and Investigative Approach section for each site. Comprehensive tables show the sample identification numbers and analytical methods applied for each sample. At most SWMUs and AOCs, sampling activities consisted of collecting surface (upper interval) and subsurface (lower interval) soil samples, in addition to groundwater samples from monitoring wells installed in the shallow and deep aquifers underlying the zone. Analytical results from surface soils, shallow groundwater, and deep groundwater were used to assess possible exposure to environmental contaminants.

### *Organization*

A human health risk assessment, as defined by RAGS Part A, includes the following steps:

- *Site characterization:* Evaluation of data regarding site geography, geology, hydrogeology, climate, and demographics.
- *Data collection:* Analysis of environmental media samples, including background/reference samples.
- *Data evaluation:* Statistical analysis of analytical data to identify the nature and extent of contamination and to establish a preliminary list of COPCs based on risk-based and background screening. This list will subsequently be refined to identify COCs.
- *Exposure assessment:* Identification of potential receptors under current and predicted conditions and potential exposure pathways, and calculation/quantitation of exposure point concentrations (EPCs) and chemical intakes.



- *Toxicity assessment:* Qualitative evaluation of the adverse effects of the COPCs, and quantitative estimate of the relationship between exposure and severity or probability of effect. 1 2 3
- *Risk characterization:* A combination of the outputs of the exposure assessment and the toxicity assessment to quantify the total noncancer and cancer risk to the hypothetical receptors. 4 5 6
- *Uncertainty:* Discussion and evaluation of the areas of recognized uncertainty in human health risk assessments in addition to medium- and exposure pathway-specific influences. 7 8
- *Risk/Hazard Summary:* Presentation and discussion of the results of the quantification of exposure (risk and hazard) for the potential receptors and their exposure pathways identified under the current and future conditions. 9 10 11
- *Remedial Goal Options:* Computation of exposure concentrations corresponding to risk projections within the USEPA target risk range of  $10^{-6}$  to  $10^{-4}$  for carcinogenic COCs and HQ goals of 0.1, 1, and 3 for noncarcinogenic COCs. 12 13 14

This general process was followed in preparing the BRA for each Zone C SWMU and AOC at NAVBASE. 15 16

### 7.3 Site Characterization 17

When performing a BRA, environmental media data are compiled to determine potential site-related chemicals and exposures for each medium as outlined in RAGS Part A. The steps identifying COPCs are discussed below. 18 19 20

### **7.3.1 Data Sources**

As part of each investigation, soil, groundwater, surface water, sediment, air, and/or other environmental media samples were collected and analyzed to delineate the sources, nature, magnitude, and extent of any contamination associated with current or past site operations. The data used in the BRA for each SWMU or AOC were obtained from the results of the RFI and associated sampling activities.

### **7.3.2 Data Validation**

Data validation is an after-the-fact, independent, systematic process of evaluating data and comparing them to established criteria to confirm that they are of the technical quality necessary to support the RFI decisions. Parameters specific to the data are reviewed to determine whether they meet the stipulated DQOs. The quality objectives address five principal parameters: precision, accuracy, completeness, comparability, and representativeness. To verify that these objectives are met, field measurements, sampling and handling procedures, laboratory analysis and reporting, and nonconformances and discrepancies in the data are examined to determine compliance with appropriate and applicable procedures.

Data for Zone C were validated in accordance with the USEPA CLP Functional Guidelines and are discussed in Section 4, Data Validation, of this report. Complete data validation reports for the Zone C dataset are included in Appendix E. In its validated form, the Zone C dataset was deemed usable for assessing risk. Chlorinated dibenzodioxin and dibenzofuran data were closely scrutinized because the analytical laboratory departed from standard analytical methods. Although each SDG was not similarly affected, some chlorinated dibenzodioxin and dibenzofuran data were qualified as EMPC during data validation. Projected human health or ecological risk estimates based on these EMPC-qualified results are likely representative of the absolute maximum potential exposure and should be considered highly conservative.

### 7.3.3 Management of Site-Related Data

All environmental sampling data were evaluated for suitability of use in the quantitative BRA. Data obtained via the following methods were not appropriate for the quantitative BRA:

- Analytical methods that are not specific to a particular chemical, such as TOC or total organic halogen.
- Field screening instruments, including total organic vapor monitoring units and organic vapor analyzers.

Because duplicate samples were collected for QA/QC, in some instances more than one analytical result existed for a single sample location. One objective of data management was to provide one result per sample location per analyte. The mean of duplicate sample results was used as the applicable value, unless the analyte was detected in only one duplicate sample. In such cases, the detection results were used.

In addition, the BRAs addressed limitations of analytical results by including estimated concentrations for nondetected parameters. A nondetect indicates that the analyte did not exceed the quantitation limit of the sample (*U*-qualified results), which is determined by the analytical method, the instrument used, and possible matrix interferences. However, a nondetected analyte could be present at any concentration between zero and the quantitation limit. For this reason, one-half the *U* value could serve as an unbiased estimate of the nondetect. Because the estimated values of *J*-qualified hits were frequently much lower than the sample quantitation limits of *U*-qualified nondetects for organic compounds, one-half of each *U* value was compared to one-half of the lowest hit (normally *J*-qualified) at the same site. The lesser of these two values was used as the best estimate of the concentration that was potentially present below the sample quantitation limit, and was inserted into the adjusted dataset.

For inorganic chemicals, the decision rule was less complex: one-half of each *U* value represented the concentration of the corresponding sample when compiling the adjusted dataset. If two nondetects were reported for any one location (a result of QA/QC samples), one-half the lesser of the *U* values was compared to the lowest hit at the site (for organics, as above) or applied directly (for inorganics) to estimate a concentration value to be used in the Zone C RFI risk calculations. If a parameter was not detected at a SWMU/AOC, neither data management method was applied, and the parameter was not considered in screening or formal assessment.

Once the dataset was complete (i.e., after elimination of faulty data, consolidation of duplicate data values, and quantification of censored values), statistical methods were used to evaluate the RFI analytical results to: (1) identify COPCs and (2) establish EPCs at potential receptor locations. The statistical methods used in data evaluation are discussed below. The rationale used to develop this methodology and the statistical techniques to implement it are based on the following sources:

- RAGS Part A
- *Statistical Methods for Environmental Pollution Monitoring* (Gilbert, 1987)
- *Supplemental Guidance to RAGS: Calculating the Concentration Term* (USEPA, 1992e)

Microsoft FoxPro, Borland Quattro Pro, and Minitab for Windows<sup>1</sup> were used to manage data and calculate statistics. For each set of data describing the concentration of chemicals in a contaminated area, the following information was tabulated: frequency of detection, range of detected values, average of detected concentrations, and the calculated 95th percentile upper confidence limit (UCL) on the mean of log transformed values of the concentration. In accordance

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<sup>1</sup> Reference to specific software products are not to be construed as a endorsement by the U.S. Navy or E/A&H.



with RAGS, the lesser of either the maximum concentration detected or the UCL was used to quantify potential exposure. This procedure is detailed in Section 7.3.6 of this document.

#### **7.3.4 Selection of Chemicals of Potential Concern**

The objective of this section of the BRA was to screen the available information on the substances detected (CPSSs) at each SWMU or AOC to develop a list or group of COPCs. COPCs are those chemicals selected by comparison with screening concentrations (risk-based and reference), intrinsic toxicological properties, persistence, fate and transport characteristics, and cross-media transport potential. For any COPC to be considered a COC, thus warranting assessment relative to corrective measures, it must meet two criteria. First, the COPC must contribute to an exposure pathway with an incremental lifetime excess cancer risk (ILCR) in excess of  $10^6$  or hazard index (HI) greater than 1 for any of the exposure scenarios evaluated in the risk assessment. Secondly, the COPC must have an individual risk projection greater than  $10^6$  or an HQ greater than 0.1. ILCR, HQ, and HI are detailed in Sections 7.3.7 and 7.3.8 of this report.

Before evaluating the potential risks/hazards associated with site media, it was first necessary to delineate the contamination onsite. This was accomplished by noting the chemicals detected in environmental media. These chemicals represent the CPSSs for each SWMU or AOC. The nature and general extent of CPSSs at each site are discussed in detail in Section 10 of the RFI. Because human health risk and hazard will ultimately direct remedial action, detailed discussions of COC extent were deferred to site-specific BRAs. The Risk Characterization section of each BRA provides risk and hazard maps for COCs (where data support such depictions) to provide visual aids in interpreting the risk assessment outputs. Where data do not support development of relevant visual presentations, affected locations are discussed for each medium. To reduce the list of CPSSs and thereby focus the risk assessment on COPCs, two comparisons were performed as described below.



#### 7.3.4.1 Comparison of Site-Related Data to Risk-Based Screening Concentrations

The maximum concentrations of CPSSs detected in samples were compared to risk-based screening values. These values were obtained from *Determination of COCs by Risk-Based Screening, USEPA Region III*, March 18, 1994, and subsequent versions. As stated in the USEPA Region III document, a target HQ of 0.1 and a risk goal of  $10^{-6}$  were used by USEPA to calculate screening concentrations for noncarcinogens and carcinogens, respectively. In instances where use of a more recent version of USEPA Region III's RBC tables was necessary, noncarcinogenic chemical values were adjusted to equate with an HQ of 0.1.

Groundwater (and surface water, where applicable) results were compared to tap water screening values, and reported soil (and sediment, where applicable) concentrations were compared to residential soil ingestion screening values. The soil screening value for lead was set equal to 400 mg/kg, consistent with recent OSWER directives considering protection of a hypothetical child resident; the lead groundwater screening value used was the USEPA Office of Water treatment technique action level (TTAL) of 15  $\mu\text{g/L}$ .

A soil screening value of 1  $\mu\text{g/kg}$  (1,000 pg/g as 2,3,7,8-TCDD TEQs) was applied to chlorinated dibenzodioxine and dibenzofurans, based on a worker/industrial scenario and the target risk of  $1\text{E-}4$ . USEPA Region IV has determined this to be an appropriate cleanup level although typically a residential scenario and a target risk of  $1\text{E-}6$  serve as the basis for screening values. For 2,3,7,8-TCDD TEQs, USEPA Region IV supports this approach in light of the high level of uncertainty associated with dioxin exposure. For groundwater, the TEQ value computed for each sample was compared to the 2,3,7,8-TCDD tap water screening level. In accordance with recent cPAH guidance (USEPA Region IV, 1993), benzo(a)pyrene equivalents (BEQs) were computed, where appropriate, by multiplying the reported concentration of each cPAH by its corresponding TEF. The BEQ values were then summed for each sample, and the total was compared to the benzo(a)pyrene RBC value during the screening process. Subsequent exposure quantification and

risk/hazard projections for cPAHs in soil and groundwater were performed using total BEQ values for each sampling location rather than individual compound concentrations.

CPSSs with maximum detected concentrations exceeding their corresponding concentrations, goals, levels, and/or standards were retained for further evaluation and reference screening in the risk assessment. Screening values based on surrogate compounds were used if no screening values were available in USEPA's table. Surrogate compounds were selected based on structural, chemical, or toxicological similarities.

The relevance of groundwater RBC screening is discussed in Sections 7.3.6 and 7.3.8. Because shallow and deep groundwater beneath most areas of Zone C contains chlorides and/or total dissolved solids (TDS) above South Carolina potable source criteria, water from these aquifers is not appropriate for domestic use. Consequently, screening the concentrations of compounds detected in groundwater against tap water RBCs provides a highly conservative assessment of the significance of groundwater impacts.

For CPSSs found in both soil (all depths) and shallow groundwater, an additional risk-based screening process was performed as part of the fate and transport assessment. Maximum soil concentrations were compared to the soil-to-groundwater cross-media protection values provided in the USEPA *Soil Screening Guidance: Technical Background Document*, May 1996 and *Risk-Based Concentration Table*, January-June 1996, (USEPA Region III, June 1996). The general approach was described in Section 6 and site-specific evaluations are presented in Section 10.

#### 7.3.4.2 Comparison of Site-Related Data to Background Concentrations

Soil and groundwater background concentrations were determined on a zone-wide basis in Zone C, using results from the grid-based soil and groundwater background sampling locations. Surface

soil, subsurface soil, and shallow and deep groundwater were all addressed separately as discussed in Section 5. Statistical methods and rationale for determining background concentrations and comparing site data to background were also outlined in Section 5. After risk- and hazard-based screening values were compared, COPCs whose maximum detected concentrations exceeded corresponding background reference concentrations, or whose overall site concentrations were significantly greater than corresponding overall background concentrations as determined by Wilcoxon rank sum test procedures, were retained for further consideration as COCs in the BRA on a SWMU- or AOC-specific basis. The two statistical background comparisons were conducted as parallel analyses. If either method suggested that site-specific concentrations deviated from naturally occurring levels, the chemical was retained for formal risk assessment. These comparisons help account for chemicals that are common in nature, such as aluminum, manganese, and arsenic. By virtue of this process, risk and/or hazard associated with naturally occurring chemicals is not addressed where their concentrations are not above corresponding background.

The background reference concentration (UTL) is a fixed value determined to represent the upper bound of naturally occurring levels for a chemical in a specific matrix. Comparisons using reference concentrations are most effective in identifying "hot spots" or limited areas with pronounced impacts. Population tests, in this case performed using the Wilcoxon rank sum method, are used to determine whether values from one population (the site samples) are consistently higher or lower than those from another (the entire background dataset). Ideally, population tests identify general elevations in chemical concentrations absent definable hot spots. A detailed discussion of statistical methods, UTL calculations, Wilcoxon rank sum test outputs and general background sample information is provided in Section 5. In the RFI, if the maximum concentration of a CPSS was determined to be less than either background (via reference concentration comparison *and* population test) or the risk-based screening value, the CPSS was not considered further in the risk assessments unless deemed appropriate based on chemical-specific characteristics (e.g. degradation product with greater toxicity).



#### 7.3.4.3 Elimination of Essential Elements: Calcium, Iron, Magnesium, Potassium, and Sodium

In accordance with RAGS Part A, essential elements that are potentially toxic only at extremely high concentrations may be eliminated from further consideration as COPCs in a risk assessment. Specifically, an essential nutrient may be screened out of a risk assessment if it is present at concentrations that are not associated with adverse health effects. Based on RAGS, the lack of risk-related data, and USEPA Region IV's recommendations, the following essential nutrients were eliminated from the human health risk assessment: calcium, iron, magnesium, potassium, and sodium.

#### 7.3.4.4 Summary of COPCs

The results of the screening evaluations are presented on a medium-specific basis in each BRA in Section 10. In summary, the risk information usually obtained from the Integrated Risk Information System (IRIS) or Health Effects Assessment Summary Tables (HEAST) is necessary to calculate risk and hazard estimates (and risk-based screening values). This information is based on toxicological and epidemiological data which are critiqued and approved by the scientific and regulatory community (i.e., listed in IRIS and/or HEAST). Risk information was not available for some CPSSs; therefore, it was not possible to calculate risk and/or hazard for those chemicals. For each environmental medium sampled at a SWMU or AOC, the data were screened using risk-based and background values. The results of the screening process are presented in tabular format in each BRA. Those chemicals determined to be COPCs through the screening process are designated with an asterisk. Total isomer concentrations reported for chlorinated dibenzodioxins and dibenzofurans (e.g., "Total HxCDD") were not specifically used in formal assessment per USEPA protocol. Instead, exposure was estimated for each individually quantitated congener (e.g., "123478-HxCDD"). No risk-based screening values are available for the generic group, TPH. As a result, TPH assessment was handled consistent with state underground storage tank (UST) regulations and the NAVBASE soil action level of 100 mg/kg. If no groundwater impacts

were identified, the existing soil concentrations were considered sufficiently protective of the underlying aquifer.

### **7.3.5 Calculation of Risk and Hazard**

As previously discussed, CPSSs that exceed their respective screening values are considered COPCs. The subsequent identification of COCs is a two-phase process. First, exposure pathways exceeding the screening criteria established by USEPA and SCDHEC are identified. Identifying COCs from the refined list of COPCs involves calculating chemical-specific cancer risks and HQs for COPCs, estimating exposure-pathway risk/hazard, evaluating frequency and consistency of detection and relative chemical toxicity, and comparing them to background concentrations. In the next step, COPCs which individually exceed  $10^6$  ILCR or an HQ greater than 0.1 in a pathway of concern (i.e., an exposure pathway having ILCR greater than  $10^6$  or HI greater than 1 are retained as COCs. Section 7.3.7 discusses cancer risk thresholds and noncancer toxicity.

### **7.3.6 Exposure Assessment**

This section of the BRA determines the magnitude of contact that a potential receptor may have with site-related COPCs. Exposure assessment involves four stages:

- Characterizing the physical setting and land use of the site
- Identifying COPC release and migration pathway(s)
- Identifying the potential receptors, under various land use or site condition scenarios, and the pathways through which they might be exposed
- Quantifying the intake rates, or contact rates, of COPCs



### **7.3.6.1 Exposure Setting and Land Use**

This section of each BRA describes the basic layout of the SWMU or AOC as well as the suspected source(s) of contamination. Where multiple SWMUs and AOCs were combined for the RFI, the rationale for grouping is discussed. In addition, the projected future use of the site is discussed if information was available. Present land use in Zone C is comparable to commercial office and residential uses. Current base reuse plans call for continued office/training settings, with small portions of the property set aside as open space/buffer and housing.

At some SWMUs/AOCs, existing site features such as asphalt surfaces, buildings, and fences would prevent and/or minimize exposure to impacted media if they are maintained under base reuse plans. As part of each site-specific BRA, the potential influences of existing site features on exposure was evaluated. Where current site features affect how an individual might be exposed, detailed analyses were performed to calculate alternate EPCs and to derive factors to account for fraction ingested/contacted from the contaminated source. The assessments performed in consideration of existing features are presented as an additional exposure scenario within the quantification of exposure and risk characterization sections of the site-specific BRAs.

### **7.3.6.2 Potentially Exposed Populations**

In each site-specific BRA, this section describes who may be exposed to contaminants in environmental media. For the Zone C BRAs, the potentially exposed populations addressed were current and future site workers, as well as hypothetical future site residents. Because current site workers at most sites within Zone C would be expected to have limited contact with contaminated media, worker-related exposure was addressed exclusively for maximally exposed future site workers. This approach, while providing a reasonably conservative assessment of future site worker risk/hazard, also renders a highly conservative approximation of risk/hazard for current site workers. It also accounts for the fact that the specific nature of future industrial users cannot be definitively stated.

### **7.3.6.3 Exposure Pathways**

This section of each BRA summarizes how potential receptors (site workers, residents, etc.) may be exposed to contaminated media. In general, soil matrix-related pathways include incidental ingestion and dermal contact. For groundwater, ingestion and inhalation of volatilized contaminants were the primary pathways of exposure evaluated. Soil-to-groundwater and soil-to-air cross-media protection factors are also discussed where appropriate.

### **7.3.6.4 Exposure Point Concentrations**

The EPC is the concentration of a contaminant in an exposure medium that will be contacted by a real or hypothetical receptor. Determining the EPC depends on factors such as:

- Availability of data
- Amount of data available to perform statistical analysis
- Reference concentrations not attributed to site impacts
- Location of the potential receptor

USEPA Region IV guidance calls for assuming lognormal distributions for environmental data and calculating the 95th percentile UCL on the mean to quantify exposure. Applying the UCL is generally inappropriate with fewer than 10 samples. The maximum concentrations detected were used for all datasets with fewer than 10 samples. In general, outliers have been included when calculating the UCL because high values seldom appear as outliers for a lognormal distribution. Including outliers increases the overall uncertainty of the calculated risks and conservatively increases the estimate of the human health threat.

For sample sets of 10 and greater, the UCL was calculated for a lognormal distribution as follows:

$$UCL = e^{\left( \bar{a} + 0.5s_a^2 + \frac{H_{0.95} s_a}{\sqrt{n-1}} \right)}$$

where:

- $\bar{a}$  =  $\Sigma a/n$  = sample arithmetic mean of the log-transformed data,  $a = \ln(x)$
- $s_a$  = sample standard deviation of the log-transformed data
- $n$  = number of samples in the dataset
- $H_{0.95}$  = value for computing the one-sided upper 95% confidence limit on a lognormal mean from standard statistical tables (Gilbert, 1987)

The calculated values for the 95% UCL are presented in tabular format (where applicable) in each BRA. The tables statistically summarize COPCs identified in each environmental medium. Included for each COPC are the number of samples analyzed, mean and standard deviation of the natural log-transformed data (including the nondetect values), the  $H$ -statistic, the maximum of detected concentrations, and background concentrations (where available). For media from which fewer than 10 samples were collected, the maximum of positive detections of each COPC identified was used as the EPC to compute exposure.

Modified or alternate EPCs were calculated for some SWMUs/AOCs because existing features or skewed contaminant distributions had to be considered in quantifying exposure potential. The modified EPCs were derived to account for the fraction of impacted areas covered with asphalt surface, buildings, and the like. Should existing features be maintained under the future industrial site use, direct exposure to affected areas (surface soil) would be effectively precluded. In some



instances, factors were derived to modify the EPC to account for the fraction ingested/contacted (FI/FC) from the contaminated source. This approach was used where impacts were found to be extremely limited in areal extent (hot spots). Where this approach was taken, the basis for the decision is discussed in the site-specific BRA.

As previously discussed in the data management subsection (Section 7.3.3) of this document, analytical results are presented as "nondetects" whenever chemical concentrations in samples do not exceed the detection or quantitation limits for the analytical procedures as applied to each sample. Generally, the quantitation limit is the lowest concentration of a chemical that can be reliably quantified above the normal, random noise of an analytical instrument or method. To apply the above-mentioned statistical procedures to a dataset with reported nondetects for organic compounds, the lesser of one-half of the nondetect value for the sample or the lowest *J*-qualified value at the site was assumed to be the applicable default concentration. For inorganic chemicals, one-half of the nondetect value was assumed to be the applicable concentration. Using this method is a reasonable compromise between use of zero and the sample quantitation limit to reduce the bias (positive or negative) in the calculated UCL.

#### **7.3.6.5 Quantification of Exposure**

This section describes the models, equations, and input parameter values used to quantify doses or intakes of the COPCs for the surface soil and groundwater exposure pathways. The models are designed to estimate route- and medium-specific factors, which are multiplied by the EPC to estimate chronic daily doses. The intake model variables generally reflect 50th or 95th percentile values which, when applied to the EPC, ensure that the estimated intakes represent the reasonable maximum exposure (RME). Formulae were derived from RAGS, Part A unless otherwise indicated. Table 7.1 lists input parameters used to compute chronic daily intake (CDI) for potential receptors exposed to surface soil and/or groundwater contaminants. These soil and groundwater pathway assumptions were applied for each SWMU and AOC in Zone C. Where

other exposure routes/pathways were found (or predicted) to exist, additional exposure quantification formulae are presented. Because NAVBASE is currently part of BRAC III and final plans for reuse of all areas are not available, the future condition and use of Zone C cannot be assumed with much certainty. Therefore, the conservative assumptions were used to account for any reasonable future use. Current plans call for mixed use including open space, offices, light industrial, and a limited amount of residential area. Zone C media analytical results and exposure methods have been formatted to fine tune exposure estimates based on actual conditions as base reuse plans materialize. Age-adjusted ingestion factors were derived for the potential future residential receptors (resident adult and resident child combined) for carcinogenic endpoints. These factors consider the difference in daily ingestion rates for soil and drinking water, body weights, and exposure durations for children (ages 1 to 6) and adults (ages 7 to 31). The exposure frequency is assumed to be identical for the adult and child exposure groups.

Table 7.1  
 Parameters Used to Estimate CDI at RME

Pathway Parameters	Resident Adult	Resident Child	Adult Worker	Units
<b>Surface Soil Ingestion and Dermal Contact</b>				
Ingestion Rate (soil)	100 <sup>a</sup>	200 <sup>a</sup>	50 <sup>a</sup>	mg/day
Ingestion Rate (water)	2	1	1	L/day
Exposure Frequency	350 <sup>b</sup>	350 <sup>b</sup>	250 <sup>b</sup>	days/year
Exposure Duration	24 <sup>c</sup>	6 <sup>c</sup>	25 <sup>c</sup>	years
Dermal Contact Area	4,100 <sup>d</sup>	2,900 <sup>d</sup>	4,100 <sup>d</sup>	cm <sup>2</sup>
Skin Adherence Factor	1	1	1	mg/cm <sup>2</sup>
Absorbance Factor	0.01 (organics) 0.001 (inorganics)	0.01 (organics) 0.001 (inorganics)	0.01 (organics) 0.001 (inorganics)	unitless
Dermal Adjustment Factor	0.8 (VOCs) 0.5 (other organic compounds) 0.2 (inorganics)	0.8 (VOCs) 0.5 (other organic compounds) 0.2 (inorganics)	0.8 (VOCs) 0.5 (other organic compounds) 0.2 (inorganics)	unitless
Conversion Factor	1E-6	1E-6	1E-6	kg/mg
Body Weight	70 <sup>a</sup>	15 <sup>a</sup>	70 <sup>a</sup>	kg



**Table 7.1**  
**Parameters Used to Estimate CDI at RME**

Pathway Parameters	Resident Adult	Resident Child	Adult Worker	Units
Averaging Time, Noncancer	8,760 <sup>e</sup>	2,190 <sup>e</sup>	9125 <sup>e</sup>	days
Averaging Time, Cancer	25,550 <sup>f</sup>	25,550 <sup>f</sup>	25,550 <sup>f</sup>	days

**Notes:**

- a = USEPA (1989a) "Risk Assessment Guidance for Superfund Vol. I, Human Health Evaluation Manual (Part A)."
- b = USEPA (1991b) "Risk Assessment Guidance for Superfund Vol. I: Human Health Evaluation Manual Supplemental Guidance, Standard Default Exposure Factors," Interim Final, OSWER Directive: 9285.6-03.EPA/600/8-89/043.
- c = USEPA (1991a), "Risk Assessment Guidance for Superfund: Vol. I – Human Health Evaluation Manual (Part B, Development of Risk-based Preliminary Remediation Goals)," OSWER Directive 9285.7-01B.
- d = Resident Adult accounts for head, hands, and forearms at 90th percentile values from Table 4B.1, Exposure Factors Handbook; assumes individual is clothed with shoes, long pants, and short sleeves; rounded up from 4,090 cm<sup>2</sup>.  
Resident Child accounts for head, hands, forearms, lower leg, and feet using 90th percentile total body surface area values for male children 1 to 6 year olds (6,000 cm<sup>2</sup> assumed for 1 to 2 years old); because individual body part information is not available for 5 to 6 year olds, mean of other groups was assumed. Forearm surface area set equal to 46% of full arm; lower leg set equal to 41% of full leg measurement.
- e = Calculated as the product of exposure duration (years) x 365 days/year.
- f = Calculated as the product of 70 years (assumed lifetime) x 365 days per year.
- NA = Not applicable.

## Surface Soil Pathway Exposure

### Ingestion of COPCs in Surface Soil

The following equation is used to estimate the ingestion of COPCs in soil:

$$CDI_s = (C_s)(IR)(EF)(ED)(F)(FI)/(BW)(AT)$$

**where:**

- CDI<sub>s</sub> = ingested dose (mg/kg-day)
- C<sub>s</sub> = concentration of contaminant in soil (mg/kg)
- IR = ingestion rate (mg/day)
- EF = exposure frequency (days/year)
- ED = exposure duration (years)
- F = conversion factor (10<sup>-6</sup> kg/mg)
- FI = fraction ingested from contaminated source (unitless)
- BW = body weight (kg)
- AT = averaging time (days)

## Dermal Contact with COPCs in Surface Soil

The following equation is used to estimate intake due to dermal contact with COPCs in soil:

$$CDI_{sd} = (C_s)(CF)(EF)(ED)(F)(FC)(ABS)(AF)/(BW)(AT)$$

where:

$CDI_{sd}$	=	dermal dose (mg/kg-day)
$C_s$	=	concentration of contaminant in soil (mg/kg)
CF	=	contact factor (cm <sup>2</sup> )
EF	=	exposure frequency (days/year)
ED	=	exposure duration (years)
F	=	conversion factor (10 <sup>-6</sup> kg/mg)
FC	=	fraction contacted from contaminated source (unitless)
ABS	=	absorption factor (unitless value, specific to organic versus inorganic compounds)
AF	=	adherence factor (mg/cm <sup>2</sup> )
BW	=	body weight (kg)
AT	=	averaging time (days)

## Groundwater Pathway Exposure

### Ingestion and Inhalation of COPCs in Groundwater

The following equation is used to estimate the ingestion and/or inhalation of COPCs in groundwater:

$$CDI_w = (C_w)(IR)(EF)(ED)(FI)/(BW)(AT)$$

where:

$CDI_w$	=	ingested/inhaled dose (mg/kg-day)
$C_w$	=	concentration of contaminant in water (mg/L)
IR	=	ingestion rate (L/day)
EF	=	exposure frequency (days/year)
ED	=	exposure duration (years)
FI	=	fraction ingested from contaminated source (unitless)
BW	=	body weight (kg)
AT	=	averaging time (days)

Figures 7.1 and 7.2 provide the formulae for calculating the CDI for soil and groundwater, respectively. Tables provided in each SWMU or AOC BRA quantify exposure to environmental media through all applicable pathways. Future site worker and hypothetical site resident exposure projections are provided separately. In accordance with USEPA guidance, the potential exposure to volatiles originating from groundwater during showering and domestic use has been estimated to be equivalent to that ingested through consumption of 2 liters/day of contaminated groundwater. Although the inhalation CDI computed on this basis is equal to that for ingestion exposures, risk and/or hazard associated with inhaled volatile contaminants are characterized using toxicological values specific to the inhalation pathway (e.g., inhalation slope factors [SFs] and reference doses [RfDs]).

**Figure 7.1**  
**Formulae for Calculating CDI for Soil**

**SOIL INGESTION PATHWAY**

**Residential Scenario:**

*Noncarcinogens — Child — Residential Scenario:*

$$CDI_{NC-C} = \frac{C_s \times IR_{soil/child} \times EF_{res} \times F \times FI \times ED_{child}}{AT_{NC-C} \times BW_{child}}$$

*Noncarcinogens — Adult — Residential Scenario:*

$$CDI_{NC-A} = \frac{C_s \times IR_{soil/adult} \times EF_{res} \times F \times FI \times ED_{adult}}{AT_{NC-A} \times BW_{adult}}$$

*Carcinogens (based on a lifetime weighted average):*

$$CDI_C = C_s \left[ \frac{IR_{soil/child} \times EF_{res} \times F \times FI \times ED_{child}}{AT_C \times BW_{child}} + \frac{IR_{soil/adult} \times EF_{res} \times F \times FI \times ED_{adult}}{BW_{adult}} \right]$$

Figure 7.1 (continued)

## SOIL DERMAL CONTACT PATHWAY

### Residential Scenario:

#### Noncarcinogens — Child — Residential Scenario:

$$CDI_{NC-C} = \frac{C_s \times CF_{soil/child} \times EF_{res} \times F \times FC \times AF \times ABS \times ADJ \times ED_{child}}{AT_{NC-C} \times BW_{child}}$$

#### Noncarcinogens — Adult — Residential Scenario:

$$CDI_{NC-A} = \frac{C_s \times CF_{soil/adult} \times EF_{res} \times F \times FC \times AF \times ABS \times ADJ \times ED_{adult}}{AT_{NC-A} \times BW_{adult}}$$

#### Carcinogens (based on a lifetime weighted average):

$$CDI_C = \frac{C_s}{AT_C} \times \left[ \frac{CF_{soil/child} \times EF_{res} \times F \times FC \times AF \times ABS \times ADJ \times ED_{child}}{BW_{child}} + \frac{CF_{soil/adult} \times EF_{res} \times F \times FC \times AF \times ABS \times ADJ \times ED_{adult}}{BW_{adult}} \right]$$



**Figure 7.1 (continued)**

**Formulae for Calculating CDI for Surface Soil**

Variable	Description
$BW_{child}$	average child body weight (ages 1-6) (kg)
$BW_{adult}$	average adult body weight (kg)
ABS	absorbance factor (unitless value specific to organic versus inorganic compounds)
ADJ	dermal to absorbed dose adjustment factor (unitless value specific to VOCs, SVOCs, and inorganic compounds)
AF	adherence factor (1 mg/cm <sup>2</sup> )
$ED_{child}$	child exposure duration during (ages 1-6) (yr)
$ED_{adult}$	adult exposure duration during (ages 7-31) (yr)
$ED_{adult-w}$	adult worker exposure duration during (yr)
$EF_{res}$	residential exposure frequency (days/year)
$EF_w$	worker exposure frequency (days/year)
$IR_{soil/child}$	child soil intake rate (mg/day)
$IR_{soil/adult}$	adult soil intake rate (mg/day)
FC	fraction contacted from contaminated source (unitless)
$CF_{soil/child}$	child soil dermal contact factor (mg/day)
$CF_{soil/adult}$	adult soil dermal contact factor (mg/day)
$AT_C$	averaging time (carcinogen)
$AT_{NC-A}$	averaging time (noncarcinogen adult)
$AT_{NC-C}$	averaging time (noncarcinogen child)
$C_s$	chemical concentration in surface soil (mg/kg)
FI	fraction ingested from contaminated source (unitless)
F	conversion factor (10 <sup>-6</sup> kg/mg)

**Notes:**

CDI indicates Chronic Daily Intake

The worker scenario risk and hazard were calculated by substituting worker-specific assumptions into the adult portions of the formulae and then deleting the child portions of the formulae.

**Figure 7.2**

**Formulae for Calculating CDI for Groundwater**

**GROUNDWATER INGESTION PATHWAY**

**Residential Scenario:**

*Noncarcinogens — Child — Residential Scenario:*

$$CDI_{NC-C} = \frac{C_w \times IR_{\text{water/child}} \times EF_{\text{res}} \times ED_{\text{child}} \times FI}{AT_{NC-C} \times BW_{\text{child}}}$$

*Noncarcinogens — Adult — Residential Scenario:*

$$CDI_{NC-A} = \frac{C_w \times IR_{\text{water/adult}} \times EF_{\text{res}} \times ED_{\text{adult}} \times FI}{AT_{NC-A} \times BW_{\text{adult}}}$$

*Carcinogens (based on a lifetime weighted average):*

$$CDI_C = \frac{C_w}{AT_C} \left[ \frac{IR_{\text{water/child}} \times EF_{\text{res}} \times ED_{\text{child}} \times FI}{BW_{\text{child}}} + \frac{IR_{\text{water/adult}} \times EF_{\text{res}} \times ED_{\text{adult}} \times FI}{BW_{\text{adult}}} \right]$$

**Figure 7.2 (continued)**

**Formulae for Calculating CDI for Groundwater**

**PATHWAY: GROUNDWATER INHALATION WHILE SHOWERING**

**Residential Scenario:**

In accordance with *Technical Memorandum Guidance on Estimating Exposure to VOCs During Showering*, USEPA/ORD, July 10, 1991:

$$CDI_{\text{ingestion}} = CDI_{\text{inhalation}}$$

Variable	Description
$BW_{\text{child}}$	average child body weight (ages 1-6) (kg)
$BW_{\text{adult}}$	average adult body weight (kg)
$ED_{\text{child}}$	child exposure duration during (ages 1-6) (yr)
$ED_{\text{adult}}$	adult exposure duration during (ages 7-31) (yr)
$ED_{\text{adult-w}}$	adult worker exposure duration during (yr)
$EF_{\text{res}}$	residential exposure frequency (days/year)
$EF_{\text{w}}$	worker exposure frequency (days/year)
$IR_{\text{water/child}}$	child water intake rate (mg/day)
$IR_{\text{water/adult}}$	adult water intake rate (mg/day)
$FI$	fraction ingested from contaminated source (unitless)
$AT_{\text{C}}$	averaging time (carcinogen)
$AT_{\text{NC-A}}$	averaging time (noncarcinogen adult)
$AT_{\text{NC-C}}$	averaging time (noncarcinogen child)
$C_{\text{w}}$	chemical concentration in groundwater (mg/L)

**Notes:**

CDI indicates Chronic Daily Intake

The worker scenario risk and hazard were calculated by substituting worker-specific assumptions into the adult portions of the formulae and then deleting the child portions of the formulae.

### 7.3.7 Toxicity Assessment

#### 7.3.7.1 Carcinogenicity and Noncancer Effects

The USEPA has established a classification system for rating the potential carcinogenicity of environmental contaminants based on the weight of scientific evidence. The cancer classes are described below. Cancer weight-of-evidence class "A" (human carcinogens) means that human toxicological data have shown a proven correlation between exposure and the onset of cancer (in varying forms). The "B1" classification indicates some human exposure studies have implicated the compound as a probable carcinogen. Weight-of-evidence class "B2" indicates a possible human carcinogen, a description based on positive laboratory animal data (for carcinogenicity) in the absence of human data. Weight-of-evidence class "C" identifies possible human carcinogens, and class "D" indicates a compound not classifiable for its carcinogenic potential. The USEPA has established SFs for carcinogenic compounds. The SF is defined as a "plausible upper-bound estimate of the probability of a response (cancer) per unit intake of a chemical over a lifetime" (RAGS, Part A).

In addition to potential carcinogenic effects, most substances can also produce other toxic responses at doses greater than experimentally derived threshold concentrations. The USEPA has derived RfD values for these substances. A chronic RfD is defined as *an estimate (with uncertainty spanning perhaps an order of magnitude or greater) of a daily exposure concentration for the human population, including sensitive subpopulations, that is likely to be without an appreciable risk of deleterious effects during a lifetime*. These toxicological values are used in risk formulae to assess the upper-bound level of cancer risk and noncancer hazard associated with exposure to a given contaminant concentration.

For carcinogens, the potential risk posed by a chemical is computed by multiplying the CDI (as mg/kg-day) by the SF (in reciprocal mg/kg-day). The HQ (for noncarcinogens) is computed by dividing the CDI by the RfD. The USEPA has set standard limits (or points of departure) for



carcinogens and noncarcinogens to evaluate whether significant risk is posed by a chemical (or combination of chemicals). For carcinogens, the point-of-departure range is  $10^{-6}$ , with a generally accepted range of  $10^{-6}$  to  $10^{-4}$ . These risk values correlate with a 1 in 10,000 and a 1 in 1,000,000 excess incidence of cancer resulting from exposure to xenobiotics (all pathways).

For noncarcinogens, other toxic effects are generally considered possible if the HQ (or sum of HQs for a pathway, HI) exceeds unity (a value of 1). Although both cancer risk and noncancer hazard are generally additive (within each group) only if the target organ is common to multiple chemicals, a most conservative estimate of each may be obtained by summing the individual risks or hazards, regardless of target organ. The following BRAs have taken the universal summation approach for each class of toxicant. Additional details regarding the risk formulae applied to site data are provided in the Risk Characterization section of this document.

Critical studies used in establishing toxicity classifications by USEPA are shown in the IRIS database (primary source) and/or HEAST, Fiscal Year 1995 (secondary source). If toxicological information is unavailable in IRIS or HEAST, values were obtained from reports issued by the Environmental Criteria and Assessment Office (ECAO)/National Center for Environmental Assessment (NCEA). Where applicable, these values were also included in the database for these BRAs. The BRA for each site with identified COPCs includes a table summarizing toxicological data in the form of RfDs and SFs obtained for the relevant COPCs, as well as uncertainty/modifying factors, target organs, and cancer classes (where available).

#### **7.3.7.2 Toxicity Profiles for COPCs**

In accordance with RAGS, the BRAs include brief toxicological profiles for all COPCs. Most information for the profiles was gleaned from IRIS and HEAST, as mentioned in the preceding text, and toxicological database information table. Any additional references are noted specifically



in the profiles. The profiles summarize adverse effects of COPCs and the amounts associated with such effects.

### 7.3.8 Risk Characterization

Risk characterization combines the results of the exposure assessment and toxicity assessment to yield qualitative and quantitative expressions of risk and/or hazard for the exposed receptors. The quantitative component expresses the probability of developing cancer, or a nonprobabalistic comparison of the estimated dose with a reference dose for noncancer effects. These quantitative estimates are developed for individual chemicals, exposure pathways, transfer media, and source media, and for each receptor for all media to which one may be exposed. The qualitative component usually involves comparing COC concentrations in media with established criteria or standards for chemicals for which there are no corresponding toxicity values. The risk characterization is used to guide risk management decisions.

Generally, the risk characterization follows the methodology prescribed by RAGS Part A, as modified by more recent information and supplemental guidance cited earlier. The USEPA methods are, appropriately, designed to be health-protective, and tend to overestimate, rather than underestimate, risk. The risk results, therefore, are generally overly conservative, because risk characterization involves multiplying the conservative assumptions built into the exposure and toxicity assessments.

This section of each BRA characterizes the potential health risks associated with the intake of chemicals originating from the respective site. The USEPA methods used to estimate the types and magnitudes of health effects associated with exposure to chemicals have been supplemented, where appropriate, by graphical representations of risk and hazard. The objective of presenting this supplemental information is to more clearly depict the problem areas at the relevant sites on scales specific to individual sampling points.

## Risk Characterization Methodology

Potential risks to humans following exposure to COPCs are estimated using methods established by USEPA, when available. These health-protective methods are likely to overestimate risk. Risks from hazardous chemicals are calculated for either carcinogenic or noncarcinogenic effects. Some carcinogenic chemicals may also pose a noncarcinogenic hazard. The potential human health effects associated with chemicals that produce systemic toxic and carcinogenic influences are characterized for both types of health effects. As mentioned in Section 7.3.6.5, inhalation exposure-related risk and hazard were computed using appropriate route-specific (inhalation) SFs and RfDs (where available).

Unlike the methods for estimating inhaled or ingested dose of COPCs, which quantify the dose presented to the barrier membranes (the pulmonary or gastrointestinal mucosa, respectively), dermal dose is estimated as the dose that crosses the skin and is systemically absorbed. For this reason, oral toxicity values must be adjusted to reflect the dermally absorbed dose.

Dermal RfD values and SFs are derived from the corresponding oral values. In deriving a dermal RfD, the oral RfD is multiplied by an oral absorption factor (ABF), expressed as a decimal fraction. The resulting dermal RfD is based on the absorbed dose, the appropriate value to which a dermal dose should be compared, because dermal doses are expressed as absorbed rather than administered (intake) doses. For the same reasons, a dermal SF is derived by dividing the oral SF by the ABF. The oral SF is divided rather than multiplied because SFs are expressed as reciprocal doses.

Appendix A of RAGS, Part A, states that in the absence of specific data, an assumption of 5% oral absorption efficiency would be relatively conservative. Supplemental Guidance to RAGS: Region IV Bulletin indicates that in the absence of specific data, USEPA Region IV suggests an oral to dermal absorption factor of 80% for VOCs, 50% for SVOCs, and 20% for inorganics. These

percentages (or associated fractions) were used in the BRA and are reflected in the applicable risk/hazard results.

### *Carcinogenic Effects of Chemicals*

The risk attributed to exposure to carcinogens is estimated as the probability of an individual developing cancer over a lifetime as a result of exposure to a potential carcinogen. In the low-dose range, which would be expected for most environmental exposures, cancer risk is estimated from the following linear equation (RAGS, part A):

$$ILCR = (CDI)(SF)$$

where:

ILCR	=	incremental lifetime excess cancer risk, a unitless expression of the probability of developing cancer, adjusted for reference incidence
CDI	=	chronic daily intake, averaged over 70 years (mg/kg-day)
SF	=	cancer slope factor (mg/kg-day) <sup>-1</sup>

For a given pathway with simultaneous exposure of a receptor to several carcinogens, the following equation is used to sum cancer risks:

$$Risk_p = ILCR(chem_1) + ILCR(chem_2) + \dots ILCR(chem_i)$$

where:

Risk <sub>p</sub>	=	total pathway risk of cancer incidence
ILCR(chem <sub>i</sub> )	=	incremental lifetime excess cancer risk for a specific chemical

Cancer risk for a given receptor across pathways and across media is summed in the same manner.

### *Noncarcinogenic Effects of Chemicals*

The risks associated with the noncarcinogenic effects of chemicals are evaluated by comparing an exposure level or intake with a reference dose. The HQ, defined as the ratio of intake to RfD is defined as (RAGS, Part A):

$$HQ = CDI/RfD$$

where:

HQ = hazard quotient (unitless)

CDI = intake of chemical (mg/kg-day)

RfD = reference dose (mg/kg-day)

Chemical noncarcinogenic effects are evaluated on a chronic basis, using chronic RfD values. An HQ of unity or 1 indicates that the estimated intake equals the RfD. If the HQ is greater than unity, there may be a concern for potential adverse health effects.

For simultaneous exposure of a receptor to several chemicals, an HI will be calculated as the sum of the HQs by:

$$HI = HQ_1 + HQ_2 + \dots HQ_i$$

where:

HI = hazard index (unitless)

HQ = hazard quotient (unitless)



Risk and hazard projections are summarized in tabular format for each medium following the general discussions of risk and hazard quantification methods. For most SWMUs and AOCs, the following subsections are included.

#### **7.3.8.1 Surface Soil Pathways**

This section of each BRA summarizes estimated surface soil risk/hazard for each receptor group. In addition, the primary contributors to carcinogenic risk and/or noncarcinogenic hazard are discussed.

#### **7.3.8.2 Groundwater Pathways**

This section of each BRA summarizes estimated groundwater risk/hazard for each receptor group. In addition, the primary contributors to carcinogenic risk and/or noncarcinogenic hazard are discussed.

#### **7.3.8.3 Other Applicable Pathways**

This section appears in BRAs for sites where pathways other than soil and groundwater were identified. It summarizes estimated risk/hazard for each receptor group and discusses the primary contributors to carcinogenic risk and/or noncarcinogenic hazard.

#### **7.3.8.4 COCs Identified**

This section summarizes the outcome of risk/hazard projections by identifying COCs for each impacted environmental medium. COCs are identified for each medium based on cumulative (all pathway) risk and hazard projected for each site, and are shown in tabular form (where necessary). USEPA has established a generally acceptable risk range of  $10^{-4}$  to  $10^{-6}$ , and an HI threshold of 1.0 (unity). In Zone C BRAs, a COC was considered to be any chemical contributing to a cumulative risk level of  $10^{-6}$  or greater and/or a cumulative HI above 1.0, if its individual ILCR exceeds  $10^{-6}$  or whose HQ exceeds 0.1. For carcinogens, this approach is relatively conservative,



as a cumulative risk of  $10^{-4}$  (and individual ILCR of  $10^{-6}$ ) is generally recognized by USEPA Region IV as the actionable trigger for establishing COCs. The COC selection method presented was used to provide a more comprehensive evaluation of chemicals contributing to carcinogenic risk or noncarcinogenic hazard during the RGO's development process.

Under the traditional risk-based COC trigger provisions, no carcinogenic COCs would be identified for a particular receptor group/pathway combination if the overall cumulative site risk is less than  $10^{-4}$ . However, as described in Section 7.3.7.1 of this report, the cumulative risk threshold used to identify COCs in the following BRAs is two orders of magnitude more conservative,  $10^{-6}$ .

#### **7.3.8.5 Risk/Hazard Maps**

In addition to the standard tabular presentation of risk/hazard, summary risk and hazard contour maps were plotted (where appropriate) for applicable environmental media to provide a visual supplement. When they are used in an RFI, contour maps are generally developed to show the distribution and concentration of individual chemicals or groups of chemicals, or the risk/hazard associated with potential exposure through applicable pathways.

As an extension of conventional risk/hazard determinations, risk and hazard were calculated based on each COC's concentration at each sample location. Maps were constructed for each combination of SWMU/AOC, medium, and pathway for which sufficient data were available to produce relevant contours. Maps and other graphics were prepared only when they were considered a useful aid in data interpretation and/or CMS decision-making. Narratives are provided where graphical presentations were inappropriate. If COCs were not identified in the BRA for a specific site or an adequate narrative explanation could be provided, risk contours were not developed for that site.

Surfer for Windows and ArcView, standard graphical data presentation and geographic information system packages, were used to plot the risk/hazard projections on SWMU/AOC maps. Section 7.3.9.7 describes the interpolation method used to locate the contours, and discusses the uncertainties involved in the mapping process. The contour maps illustrate risk or hazard associated with COCs in the subject medium. The risk/hazard for individual locations were based exclusively on chemicals detected. For shallow groundwater (where applicable), maps address first-quarter analytical results. Tables summarize the data used to generate graphical presentations. This information allows the reviewer to make determinations regarding the nature of the contaminants identified, and also facilitates remedial alternatives screening as part of the CMS.

### **7.3.9 Risk Uncertainty**

This section of the BRAs presents and discusses the uncertainty and/or variability inherent in the risk assessment process in addition to medium-specific and exposure pathway-specific influences. Risk assessment sections are discussed separately below, and specific examples of uncertainty sources are included where appropriate.

#### **7.3.9.1 General**

Uncertainty is a factor in each step of the exposure and toxicity assessments summarized above. Overall, uncertainties associated with the initial stages of the risk assessment process become magnified when they are combined with other uncertainties. Together, the use of high-end estimates of potential exposure concentrations, frequencies, durations, and rates leads to conservative estimates of CDI. Toxicological values for chemicals derived from USEPA databases and other sources are generally derived from animal studies. Uncertainty and modifying factors are applied to extrapolate the results of these studies to predict potential human responses, providing a margin of safety based upon confidence in the studies. During the risk characterization process, individual chemical risk is added to determine the incremental excess

cancer risk for each exposure pathway. If the individual exposure predictions were calculated based on the upper limit estimates of exposure to each chemical, the margin of safety of the cumulative incremental risk is the sum of all the individual safety margins applied throughout the process. Use of these safety margins during all exposure and risk/hazard computations provides an extremely conservative means of predicting potential human health effects. The margins of safety or "conservatisms" inherent in each step of the human health risk assessment are addressed in the Risk Uncertainty discussion. It is not possible to eliminate all uncertainties or potential variability in the risk assessment process; however, recognizing the influences of these factors is fundamental to understanding and subsequently using risk assessment results.

The Risk Uncertainty section of each BRA presents the uncertainty and/or variability of site-specific and medium/pathway-specific factors introduced as part of the risk assessment process, in addition to other factors influencing the uncertainty of the calculated incremental excess cancer risks and hazard quotients/indices. Calculated risk/hazard levels reflect the underlying variability of the analytical results that they are based on; they also embody uncertainty about potentially unsampled maxima and minima in the analytes. The exposure pathways considered for selection in the Exposure Assessment Section of the BRA are extremely conservative.

Assumptions are made as part of the risk assessment process based on population studies and USEPA guidance. This guidance divides the assumptions into two basic categories: the upper bound (90 to 95th percentile) and the mean or 50th percentile central tendency (CT) exposure assumptions. As discussed in the Exposure Assessment section, the RME exposure is based on the upper-bound assumptions, and CT exposure is based on mean assumptions. Therefore, risk and hazard calculated using RME exposure assumptions are generally overestimates rather than underestimates. The following paragraphs discuss sources of uncertainty and variability pertinent to each exposure pathway evaluated.



cancer risk for each exposure pathway. If the individual exposure predictions were calculated based on the upper limit estimates of exposure to each chemical, the margin of safety of the cumulative incremental risk is the sum of all the individual safety margins applied throughout the process. Use of these safety margins during all exposure and risk/hazard computations provides an extremely conservative means of predicting potential human health effects. The margins of safety or "conservatisms" inherent in each step of the human health risk assessment are addressed in the Risk Uncertainty discussion. It is not possible to eliminate all uncertainties or potential variability in the risk assessment process; however, recognizing the influences of these factors is fundamental to understanding and subsequently using risk assessment results.

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### 7.3.9.2 Quality of Data

Data collected during the investigation of Zone C are presented in Section 10 of this RFI, which includes results from AOC and SWMU sites and the QA/QC of those data. The purpose of the data evaluation is to verify that the QC requirements of the dataset have been met and to characterize the weakness of questionable data.

Environmental samples were collected at Zone C sites from February 1995 to August 1997 (excluding the later quarterly groundwater sampling rounds). Samples analyzed for dioxins were submitted to Southwest Laboratory. Samples analyzed for organotins were submitted to Triangle Laboratories. All other samples were analyzed by CompuChem Laboratories Inc. Ninety percent of the samples were reported using USEPA DQO Level III, while 10% were analyzed for Appendix IX parameters using USEPA DQO Level IV. The analytical methods and DQO laboratory deliverables are summarized in Section 4, Data Validation.

As noted in Section 7.3.2, most Zone C data were deemed usable for risk assessment in their qualified form. Polychlorinated dibenzodioxin and dibenzofuran data for some samples were qualified as EMPC indicating that the reported values are potentially positively biased. As a result, all exposure predictions made using data so qualified should be considered absolute maxima.

Most analytical results for environmental samples have inherent uncertainty. This uncertainty is a function of the matrix characteristics and heterogeneity, the precision and accuracy of sampling, and preparation and analysis methods employed. Although data are typically considered to be exact values, they are in reality the laboratory's best estimate within a range defined by method control limits. As a result, reported concentrations for any chemical can be under or overestimates of actual concentrations.



### 7.3.9.3 Identification of COPCs

Rather than addressing risk/hazard for all chemicals detected, screening values were used to focus the BRA on pathways of concern and COPCs which individually exceed  $10^6$  risk or an HQ of 0.1.

#### *Exposure Pathways and Contaminants*

As discussed in Section 7.3.4.1, a comparison was made using the most conservative screening value (residential land use) provided by USEPA for each exposure medium. Many CPSSs were eliminated from the formal assessment on this basis. Although potential cumulative effects associated with multiple chemicals dismissed through this process are a valid concern, the fact that maximum detected concentrations were used in the screening comparison in concert with low range risk/hazard goals alleviates much uncertainty. A large number (i.e., greater than 10) of constituents would have to be present at near-RBC concentrations to substantiate a concern for cumulative effects. Although the screening method is highly conservative, inhalation and dermal exposure are not incorporated into the soil screening values calculated by USEPA. If these pathways were the primary concern (as opposed to ingestion), the screening method could eliminate contaminants that should be considered COPCs. An evaluation of Zone C surface soil data determined that VOCs were not widespread. Therefore, soil-to-air cross-media transport (via volatilization) was not identified as a potential concern. Therefore, omitting the indirect air pathway from the process of developing the risk-based screening concentrations did not adversely affect their use.

#### *Comparison to Reference Concentrations (Background)*

Because the intent of the BRA is to estimate the excess cancer risk or health hazard posed by COPCs, individual site data values of inorganic chemicals were compared to background reference concentrations in the RFI for Zone C subsequent to comparing the data to screening values. As a corollary background screening method, the Wilcoxon rank sum test was used to compare inorganic COPC data populations at individual sites with corresponding reference data

populations. The outcomes of the fixed point and Wilcoxon tests were used to determine whether the concentrations differed significantly between onsite and background locations, as detailed in Section 7.3.4.

Additional uncertainty is introduced by comparing site data to nonspecific screening reference data. Although the background concentrations are specific to Zone C, they are not individual SWMU-specific or AOC-specific. The dual approach to background screening reduces the probability that a COPC would be improperly dismissed from formal assessment.

Background or non-site-related contamination was not considered in identifying organic COPCs for SWMUs or AOCs in Zone C. The most frequently identified soil pathway-related COPCs were cPAHs which were addressed in terms of BEQs as described in Section 7.3.4.1. The compounds that make up this group are commonly found associated with asphalt, used oils, and combustion by-products. In Zone C, all three types of cPAH source have existed at some time. During RFI activities, cPAHs were frequently detected where surface soil samples were collected in proximity to roadways and parking lots. Spatial analysis of cPAH detections indicated that asphaltic materials were not the sole source.

This material, referred to as "coal clinker," has been used extensively across the zone for road base and general fill purposes. Due to its coal origins and combustion generation process, the detection of cPAHs in soil mixed with the material is not unexpected. The characteristics of the material, including a cinder consistency, would tend to minimize coingestion with native soil. The material was present at the surface in some areas and buried beneath more recent soil fill in others. As a result, construction of a comprehensive coal clinker distribution map was not possible.

### ***Elimination of Essential Nutrients***

In accordance with RAGS, the following nutrients were eliminated from Zone C BRAs: calcium, sodium, potassium, magnesium, and iron. Toxicity from overexposure to the nutrients listed above is possible only if human receptors are exposed to extremely high doses. USEPA recommends eliminating these compounds from formal risk assessment. Because no screening comparison was performed, the HIs calculated in the BRA could be positively influenced by the nutrient concentrations detected onsite. Therefore, the HIs are possibly underestimates.

#### **7.3.9.4 Characterization of Exposure Setting and Identification of Exposure Pathways**

The potential for high bias is introduced through the exposure setting and pathway selection due to the highly conservative assumptions (i.e., future residential use) recommended by USEPA Region IV when assessing potential future and current exposure. The exposure assumptions made in the site worker scenario are highly conservative and would tend to overestimate exposure. Current site workers are not exposed to site groundwater. They are infrequently exposed to surface soils when walking across the site, using commercial facilities, or mowing the grass. Site workers would not be expected to work onsite in contact with effected media for eight hours per day, 250 days per year, as assumed in the exposure assessment. Mowing grass 52 days per year would result in one-fifth the projected risk/hazard for site workers.

Residential use of the sites in Zone C is possible, based on current site uses, the nature of surrounding buildings, and potential reuse plans. If this area were developed as residential sites, most of the present buildings would be demolished and the surface soil conditions would likely change — the existing soil could be covered with roads, paved driveways, landscaping soil, and/or houses, or they could be made into playgrounds. Consequently, exposure to current surface soil conditions would not be likely under a true future residential scenario. These factors indicate that exposure pathways assessed in the BRA would generally overestimate the risk and hazard posed to current site workers and future site residents.



To more accurately assess potential exposure under current site conditions, existing features were evaluated to determine whether they might preclude or minimize contact. Asphalt parking/road surfaces, buildings, and concrete slabs are examples of features under which soil samples were collected. Assuming the future site use involves maintaining these structures, onsite workers would not be chronically exposed to soil beneath them. These factors were considered in calculating alternative EPCs for SWMUs/AOCs with significant surface features (where applicable) and generating descriptive text where formal analysis was deemed unnecessary.

Where chronic RME estimates of risk/hazard indicate that a significant threat would be posed to human health, CT analyses were performed. CT exposure scenarios were constructed consistent with standard CT exposure assumptions provided in *Superfund's Standard Default Exposure Factors for the Central Tendency and Reasonable Maximum Exposure — Draft* (USEPA, November 1993).

Groundwater is not currently used at any Zone C location as a source of potable or process water.

A basewide system provides drinking and process water to buildings throughout Zone C. This system is to remain in operation under the current base reuse plan. As a result, shallow groundwater would not be expected to be used under future site use scenarios. Therefore, the scenario established to project risk/hazard associated with shallow groundwater exposure is highly conservative, and associated pathways are not expected to be completed in the future.

In addition, the shallow aquifer, monitored during the RFI process, naturally contains significant concentrations of chlorides and TDS. As a result, this water-bearing zone's potential as a source of potable water is questionable. Absent potential potable uses, the applicability of tap water-based screening or remedial standards is questionable.

### *Determination of Exposure Point Concentrations*

Based on the guidance provided by USEPA, EPCs are concentrations used to estimate CDI. The uncertainty associated with EPCs stems primarily from their statistical determination or the imposition of maximum concentrations, described below.

### *Statistical Estimation of Exposure Point Concentrations*

USEPA's *Supplemental Guidance to RAGS: Calculating the Concentration Term* guidance document, (May 1992), outlines a statistical estimation of EPC. These calculated concentrations are 95th percentile UCLs on the mean, which are based on certain assumptions. USEPA assumes that most (if not all) environmental data are lognormally distributed. This assumption can lead to over- or underestimation of the concentration term because many environmental data are neither normally nor lognormally distributed.

The UCL calculation method provided in the *Supplemental Guidance to RAGS: Calculating the Concentration Term*, (USEPA, May 1992), includes a statistical value, the *H*-statistic, which is based on the number of samples analyzed for each COPC and the standard deviation of the results. To obtain this number, a table must be referenced, and the value must be interpolated (an estimation) from the table. The equation for the *H*-statistic has not been provided in the supplemental guidance, nor does the document referred to in the guidance provide the equation. Although the statistic appears to be nonlinear, linearity was assumed to facilitate interpolation of the statistic for each COPC addressed in the BRAs.

Linear interpolation is a good estimate of *H*; however, the UCL formula and *H* are natural log values. The effect of multiplying natural log numbers is not equivalent to multiplying untransformed values. When data are log transformed, adding two numbers is the equivalent of multiplying the two numbers if they were not transformed. The effect of multiplying a number while in log form is exponential; and here, *H* is applied as a multiplier. In summary, using this



method to calculate the UCL has the effect of overestimating, and often provides concentrations greater than the maximum detected onsite. For all datasets having fewer than 10 total samples for a specific medium, the maximum concentrations detected were used as EPC. The datasets in these risk assessments are generally small; however, most consisted of 10 or more samples, and the UCL was calculated for those groups. The limited number of soil and groundwater samples used to assess site conditions often resulted in considerable variability between data points, and thus relatively high standard deviations about the mean. The high standard deviation elevates UCL projections.

Although RAGS advocates using neither worst-case scenarios nor maximum concentrations as EPCs, the use of the *H*-statistic often necessitates using the reported maximum concentration as the EPC. In accordance with RAGS, the lesser of either the maximum concentration or the UCL is used as the EPC. As reviewed above, summation of risk based on maximum concentrations leads to overestimation of exposure, especially in the case of low detection frequency or spatially segregated COPCs. This concept is further discussed below.

#### ***Frequency of Detection and Spatial Distribution***

Because of the influence of standard deviation on EPC, low frequency of detection can cause COPCs to be addressed inappropriately in the risk assessment. More specifically, COPCs detected only once or twice in all samples analyzed (having concentrations exceeding the RBCs and reference concentrations) would be expected to have relatively higher standard deviation as concentration variability or range widens. Higher standard deviation results in a high *H*-statistic, and this typically leads to a UCL greater than the maximum concentration detected onsite. If that is the case, then using the UCL or maximum concentration detected as EPC (or possibly the inclusion of the COPC in question) may not be appropriate when EPC is assumed to be widely distributed. It is not feasible for a receptor to be simultaneously exposed to maximum concentrations of different contaminants at several locations. The use of the maximum

concentrations (or the UCL) is questionable for these contaminants, and the calculated risk and hazard could be skewed upward or downward due to the low frequency of detection.

In some instances, it is possible to define hot spots within the investigation area. A hot spot is an isolated area of concentrated contamination within a larger area which is not impacted or much less so. Exposure quantification in the presence of a hot spot may be achieved by calculating an FI/FC from a contaminated source factor based on the percentage of the total exposure area encompassed by the hot spot, then using this term to modify the maximum (or restricted area average) contaminant concentration to derive the EPC.

#### 7.3.9.5 Toxicity Assessment Information

There is a generally recognized uncertainty in human toxicological risk values developed from experimental data primarily due to the uncertainty of data extrapolation in the areas of: (1) high-to-low-dose exposure and (2) animal data to human experience. The site-specific uncertainty is mainly in the degree of accuracy of the exposure assumptions. Most of the assumptions used in this and any risk assessment have not been verified. For example, the degree of chemical absorption from the gut or through the skin or the amount of soil contact is not known with certainty.

The uncertainty of toxicological values from the IRIS and HEAST databases provided by USEPA is summarized (where available) in each BRA. The uncertainty factors assigned to these values account for acute to chronic dose extrapolation, study inadequacies, and sensitive subpopulations, among other factors. Although uncertainty factors for a specific compound may be 1,000 or higher, these safety factors are applied by USEPA to help guarantee that the overall assessment of risk/hazard is conservative toward human health concerns. In the presence of such uncertainty, the USEPA and the risk assessor are obligated to make conservative assumptions so that the chance is very small for the actual health risk to be greater than what is determined through the

risk assessment process. On the other hand, the process is not intended to yield overly conservative risk values that have no basis in actual conditions. This balance was kept in mind in developing exposure assumptions and pathways and in interpreting data and guidance for Zone C BRAs.

#### *Evaluation of Dioxin Congeners as 2,3,7,8-TCDD Equivalents*

Where chlorinated dibenzodioxins and dibenzofurans (dioxins) were detected in soil, TEQs were derived by multiplying the concentration of each dioxin congener by its corresponding USEPA TEF. The resulting TEQs were then summed for each sample, and the total was compared to the 1  $\mu\text{g}/\text{kg}$  AL. If the total TEQ value was found to be less than 1  $\mu\text{g}/\text{kg}$ , it was concluded that soil dioxins do not pose an unacceptable risk. Groundwater exposure quantification was performed using TEQ values computed for each monitoring point.

#### *Evaluation of Chemicals for Which No Toxicity Values Are Available*

In addition to the typical uncertainties inherent in toxicity values, parameters that do not have corresponding RBCs due to the lack of approved toxicological values were not included in the CDI calculation data. This does not indicate that chemicals lacking approved toxicological values pose no risk/hazard. As stated previously, essential nutrients were eliminated based on their low potential for toxicity. Therefore, these chemicals were not assessed further in the BRA.

#### **7.3.9.6 Quantification of Risk/Hazard**

This section of each BRA is reserved for discussion of potential sources of uncertainty or variability identified in the quantification of risk and hazard that are not covered in preceding sections. Each exposure medium addressed in the formal risk assessment process is discussed briefly.



#### **7.3.9.7 Mapping Risk/Hazard**

Risk and hazard maps developed to present site-specific BRA results are in Section 10. Location-specific totals were summed and plotted to illustrate total risk and/or total hazard at sites where data supported such a representation. The methods used to construct the risk/hazard contour maps are discussed below. For most sites, point maps were constructed to show the cumulative risk/hazard computed at a specific point based on the location-specific data for the medium of interest. There were, however, instances where contouring the projected risk/hazard values was useful for scoping corrective measures. The following paragraphs discuss how contour maps were produced as well as sources of uncertainty inherent in any interpolation contouring process.

Contouring involves fitting isolines of elevation, concentration, risk, etc., to a scattered or gridded set of points with known values. The graphical result estimates a continuous surface. Because values are known at only a few of an infinite number of possible points on the surface, the mapping process involves extensive interpolation between known points to give estimated values.

Of many possible interpolation methods, kriging is, statistically, the best linear unbiased estimator. It provides more accurate estimates than other methods because it considers the variance of the underlying data values versus the distance between the data points. The relationship between variance and distance is modeled for each dataset using a variogram, and the model serves to differentially weight the data from nearby points with known values that are used to estimate values at unmeasured points (i.e., points whose values must be interpolated between known points). Spatial trends in the data can be recognized by specifying a "drift" (linear, quadratic, etc.), while any known error variance in the data allows use of a "nugget value" when determining the type of variogram model to be used. Risk/hazard maps for this RFI report were generated using Surfer for Windows default linear variogram model with no drift specified. The nugget value is automatically set to zero for the linear model.

Any method of contour mapping, manual or automatic, involves extensive estimation of values at unmeasured points. The mapping process itself is a generalization, in that it converts point data to area (surface) data. The resulting mapped surfaces are known to be accurate only near the control points (that is, within and immediately around the AOCs/SWMUs); accuracy decreases dramatically where there are large spatial gaps between clusters of points, as is the case in parts of Zone C. In these areas, the maps should be considered rough indicators of trends, rather than reliable sources of accurate data values at specific points.

Risk and hazard projection mapping is useful in risk assessment for determining whether hot spots (or isolated areas of gross contamination) exist within an otherwise unimpacted area. This is important, as the lack of homogeneous contaminant concentrations can affect the manner in which receptors are exposed to the affected media. As discussed earlier, it is sometimes appropriate to estimate the FI/FC from the contaminated source in computing CDI. Contour maps allow for visual analysis of contaminant distributions and facilitate estimation of the extent of hot spots relative to the overall site area. These maps also support preliminary scoping of remedial requirements as well as assessment of potential cleanup alternatives in the CMS.

As discussed above, lower confidence can be placed in the concentration estimates made by the kriging function (as represented by contours) in low sample density areas. Because the RFI focused on AOCs/SWMUs, concentrations of background samples that were collected between the sites were not incorporated into the contours, although these areas could influence risk/hazard plots developed for Zone C. In addition, any COC that was detected in only one sample location per AOC/SWMU was not included in the calculations or contours. The distribution of samples collected precluded meaningful graphical presentations at many AOCs/SWMUs. Because of the lack of calculated values for surrounding background locations, relatively planar risk/hazard results were computed for some AOC/SWMU and media combinations. Essentially "flat" plots would be of little use in interpreting risk/hazard projections. As a result, graphical outputs fitting



this description were not generated, and narrative discussions of contaminant distribution are provided instead. The contour maps presented in Section 10 of this RFI report represent the spatially distributed risk and/or hazard of COCs identified in the risk assessment.

#### **7.3.10 Risk Summary**

In each site-specific BRA, this section summarizes the risk and hazard projected for each receptor group, exposure medium, and exposure pathway.

#### **7.3.11 Remedial Goal Options**

RGOs are chemical concentrations computed to equate with specific risk and/or hazard goals that may be established for a particular site. As previously discussed, COCs are identified as any COPC that significantly contributes to a pathway of concern. A pathway having an ILCR greater than  $10^{-6}$  or an HI greater than 1 is defined as a pathway of concern, and an individual chemical which contributes either  $10^{-6}$  ILCR or 0.1 HI is considered to significantly contribute to the pathway ILCR or HI. Based on this method, COCs were identified which required calculating RGOs. These are listed in the Risk Characterization section of the BRA for each site. RGOs were calculated for all COPCs contributing to a pathway risk of  $10^{-6}$  or greater. Inclusion in the RGO table does not necessarily indicate that remedial action will be required to address a specific chemical. Instead, RGOs are provided to facilitate risk management decisions.

In accordance with USEPA Supplemental RGO Guidance, RGOs were calculated at  $10^{-4}$ ,  $10^{-5}$ , and  $10^{-6}$  risk levels for carcinogenic COCs and HQ goals of 3, 1, and 0.1 for noncarcinogenic COCs. RGOs for carcinogens were based on the lifetime weighted average and the adult site worker. Groundwater RGOs for the site resident and site worker are presented in separate tables (where applicable) in each site-specific BRA. Hazard-based RGOs were calculated based on either the hypothetical child resident or the adult site worker, as noted in the each of the corresponding tables.

#### **7.4 Site-Specific Human Health Risk Assessments**

The following sections present the human health risk assessment organization prepared for individual SWMUs and AOCs grouped for the RFI. The BRAs were organized as described in the following paragraphs.

##### **SWMU 44**

This site is presented as a stand-alone section; no other SWMUs/AOCs were included in the assessment.

##### **AOC 516 and SWMU 47**

The soil and groundwater investigations at these two sites resulted in an overlapping sampling effort. Due to their proximity, the data for these sites were combined for use in a composite human health risk assessment.

##### **AOCs 508 and 511**

The soil investigations at these two sites resulted in an overlapping sampling effort. Due to their proximity, the data for these sites were combined for use in a composite human health risk assessment.

##### **AOCs 515 and 519**

The soil investigations at these two sites resulted in an overlapping sampling effort. Due to their proximity, the data for these sites were combined for use in a composite human health risk assessment.

**AOC 523 (includes SWMU 49)**

The soil and groundwater investigations at these two sites resulted in an overlapping sampling effort. Due to their proximity, the data for these sites were combined for use in a composite human health risk assessment.

**AOCs 510, 512, 513, 517, 518, and 520**

Although these sites were grouped in the approved work plan because of similar investigative approach, they will be addressed in the human health risk assessment as separate stand-alone sections.

**AOC 522, Former Grease and Wash Building**

This site was designated as a AOC following RFI Work Plan approval and completion of the Zone C field activities. As a result, a work plan revision was submitted for review. This site is presented as a stand-alone section; no other SWMUs/AOCs were included.

**AOC 700, Golf Course Maintenance Building**

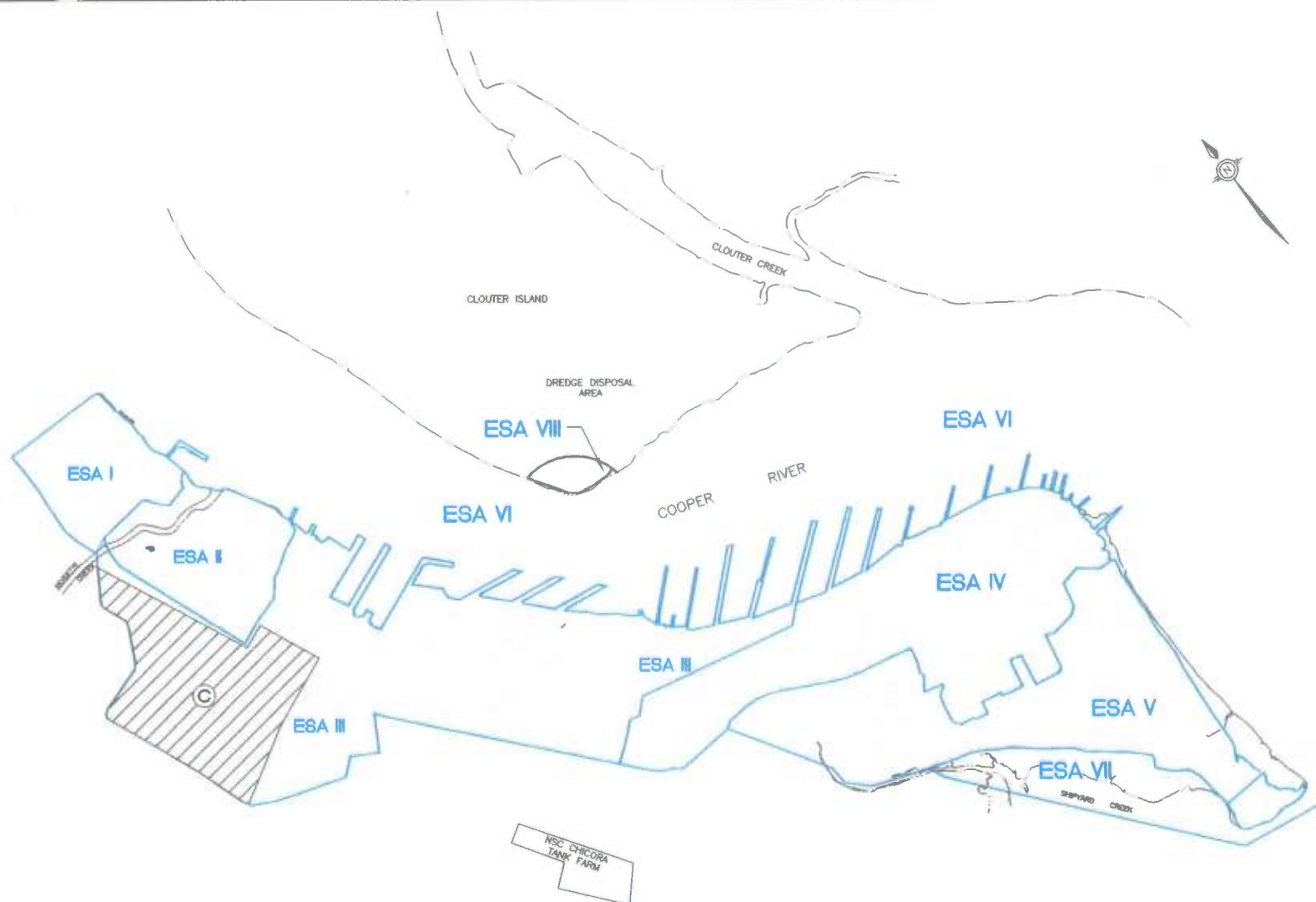
This site was designated as a AOC following RFI Work Plan approval and completion of the Zone C field activities. As a result, a work plan revision was submitted for review.

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## 8.0 ECOLOGICAL RISK ASSESSMENT

The ecological risk assessment (ERA) is a key component of a qualitative and/or quantitative ecological appraisal of the contamination on the surrounding ecosystem. The assessment of exposure pathways that could result in unacceptable risk is a foreseeable future. The approach to assessing risk components is described in the *Ecological Risk Assessment Guidance for Superfund: Part I - Ecological Risk Assessments* (Draft, USEPA, September 1992a). The approach to assessing risk components is described in the *Ecological Risk Assessment Guidance for Superfund: Part II - Environmental Evaluation Manual* (Draft, USEPA, September 1992a).





# LEGEND

- ESA BOUNDARY
- ZONE BOUNDARY

2500 0 2500  
SCALE FEET

SOURCES: SOUTH DIV, n.d. ESE, 1981.









ZONE C  
RCRA FACILITY  
INVESTIGATION REPORT  
NAVAL BASE CHARLESTON  
CHARLESTON, S.C.

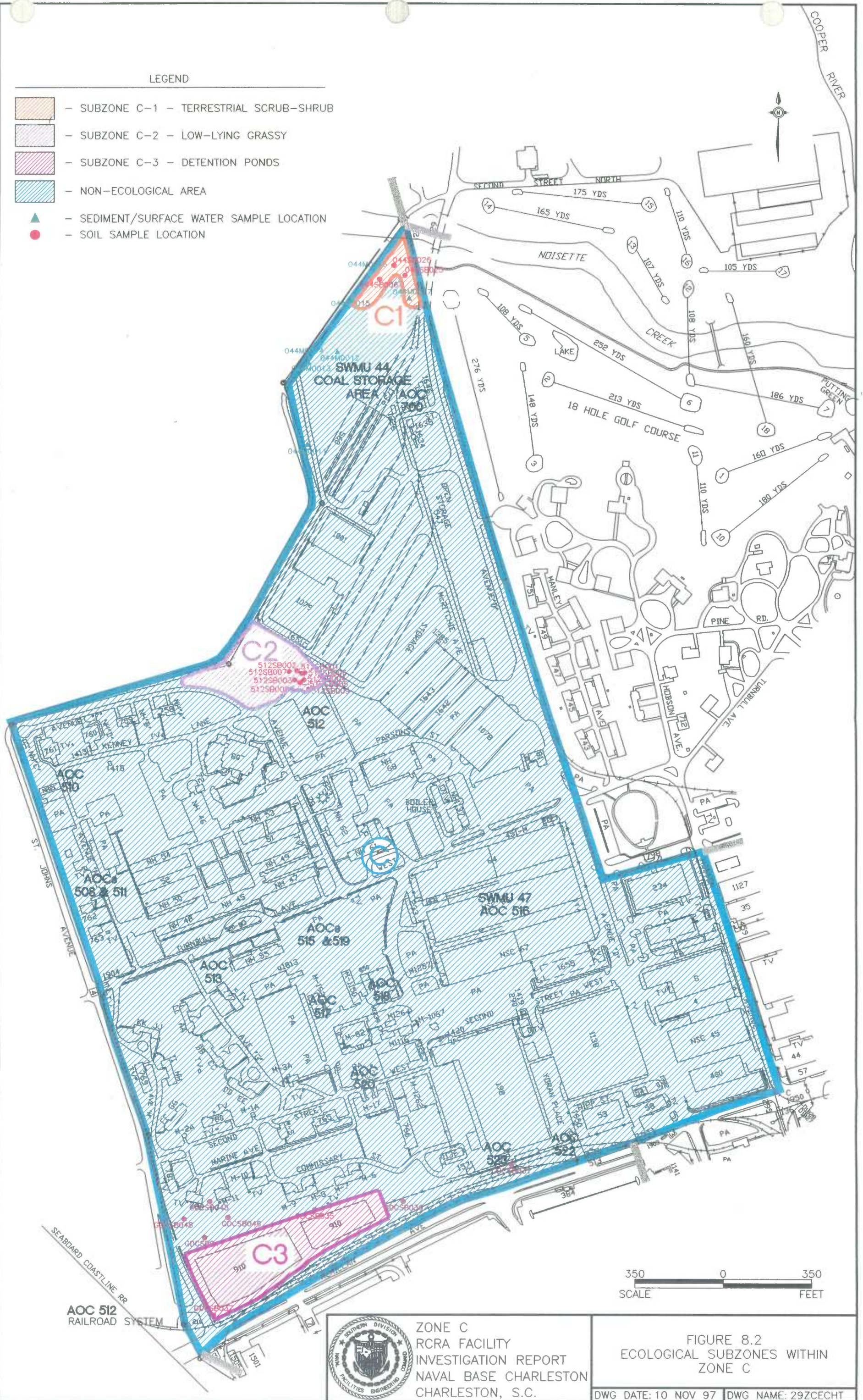
FIGURE 8.1  
ECOLOGICAL STUDY AREA  
LOCATION MAP

DWG DATE: 09/25/97 | DWG NAME: 29ECSALM3



LEGEND

-  - SUBZONE C-1 - TERRESTRIAL SCRUB-SHRUB
-  - SUBZONE C-2 - LOW-LYING GRASSY
-  - SUBZONE C-3 - DETENTION PONDS
-  - NON-ECOLOGICAL AREA
-  - SEDIMENT/SURFACE WATER SAMPLE LOCATION
-  - SOIL SAMPLE LOCATION



ZONE C  
RCRA FACILITY  
INVESTIGATION REPORT  
NAVAL BASE CHARLESTON  
CHARLESTON, S.C.

FIGURE 8.2  
ECOLOGICAL SUBZONES WITHIN  
ZONE C

DWG DATE: 10 NOV 97 | DWG NAME: 29ZCECHT

00071608Z



be discussed relative to ecological risk. Furthermore, if there is a potential for contaminant migration to aquatic areas outside of the Zone C perimeter, risk to applicable receptors in such water bodies will be evaluated during the Zone J investigation.

Subsequent to the AEC evaluations, three distinct ecological areas in Zone C, each with similar and contiguous habitats, will be addressed in this risk assessment. For the discussion purposes, these areas have been designated as Subzones C-1, C-2, and C-3 (Figure 8.2). Specific endpoints and assessment techniques are presented below. The AOCs/SWMUs within or near each subzone are identified in Table 8-1, along with nearby areas potentially impacted by those sites.

**Table 8.1**  
**AOCs/SWMUs associated with Zone C Subzones**

AOC/SWMU	Description	Potentially Impacted Areas Outside Subzone
<b>Subzone C-1</b>		
SWMU 44	Former Coal Storage Yard	Noisette Creek/Cooper River
<b>Subzone C-2</b>		
AOC 512	Former Incinerator Building	Noisette Creek/Cooper River
AOC 509	Hazardous Flammable Storage (Bldg. 1079)	Noisette Creek/Cooper River
<b>Subzone C-3</b>		
AOC 504**	Railroad System (Zone L)	Cooper River

**Note:**

\*\* AOC 504 railroads and their associated impacts are being investigated as part of the Zone L RFI. Due to the lack of identified contaminant pathways from Zone C AOC/SWMUs to Subzone C-3, no sampling has been conducted as part of the Zone C ERA.

## 8.2 Problem Formulation

### Subzone C-1 Site Description

Subzone C-1 is an approximately 0.95-acre terrestrial scrub-shrub area at the extreme northern portion of Zone C and is associated with SWMU 44 — the Coal Storage Yard. The subzone is bordered to the north by Noisette Creek and on the west by a tidally influenced storm water runoff ditch that discharges into Noisette Creek and ultimately into the Cooper River. Vegetation consists of southern bayberry (*Myrica cerifera*), tallow trees (*Sapium sevirum*), and southern red cedar (*Juniperus silicicola*), as well as dense undergrowth consisting of *Viburnum* spp. and numerous herbaceous species. Sections of this subzone bordering on Noisette Creek contain suitable habitat to support a wide variety of semiaquatic vertebrate species such as frogs (Order *Anura*), salamanders (Order *Caudata*), snakes (Order *Squamata*), and aquatic insects such as dragonflies (Order *Odonata*), mayflies (Order *Ephemeroptera*), mosquitos, and midges (Order *Diptera*). Portions of subzone C-1 provide suitable nesting and/or foraging habitat for avian species such as mourning doves (*Zenaida macroura*), yellow-rumped warblers (*Dendroica coronata*), American robin (*Turdus migratorius*), and marsh wrens (*Cistothorus palustris*). Major terrestrial faunal species typically associated with this habitat include Eastern cottontail rabbit (*Sylvilagus floridanus*) and raccoon (*Procyon lotor*), along with other small rodents (mice, voles, shrews).

### Subzone C-2 Site Description

Subzone C-2 is a 2.15-acre grassy low-lying area transected by three drainage ditches that contain small communities of cattail (*Typha* spp.) and sedges (Family *Cyperaceae*). This subzone also contains several mid-canopy trees including tallow trees, southern hackberry (*Celtis laevigata*) in addition to a woody undergrowth of *Viburnum* spp. The area is believed to be seasonally flooded by storm water runoff that drains north into an off-base marsh that empties into Noisette Creek. Avian species that may use this type of habitat include American robin (*Turdus migratorius*), common grackles (*Quiscalus quiscula*), boat-tailed grackle (*Quiscalus major*), and European



starlings (*Sturnus vulgaris*), along with birds of prey (Families *Accipitridae* and *Falconidae*). 1  
Mammals that frequent this type of habitat include the Eastern gray squirrel (*Sciurus carolinensis*), 2  
Eastern cottontail rabbit, raccoon, and other small rodents. 3

#### Subzone C-3 Site Description 4

Subzone C-3 includes a detention pond of approximately 3.75 acres which receives storm water 5  
runoff from nearby areas of NAVBASE, in addition to off-base areas. A diverse community of 6  
emergent vegetation occurs throughout the basin, making Subzone C-3 suitable habitat for a wide 7  
variety of aquatic and semiaquatic species such as reptiles and amphibians, along with a number 8  
of invertebrate species. Riparian areas of C-3 host black willow trees (*Salix nigra*) and numerous 9  
herbaceous species. Avian species observed include mourning doves (*Zenaida macroura*), 10  
northern mockingbird (*Mimus polyglottos*), red-winged blackbird (*Agelaius phoeniceus*), boat-tailed 11  
grackles, and European starlings. Mammalian species common to this type of habitat include the 12  
raccoon and Eastern cottontail rabbit, along with small rodents. 13

Due to the lack of any observed or suspected contaminant migration pathways leading from any 14  
Zone C AOC or SWMU to the Subzone C-3 detention ponds, resulting exposure potentials are not 15  
present. An assessment of ecological risk at this subzone has therefore been deemed unnecessary. 16  
Unless future RFI activities suggest additional assessment of the ponds is warranted, no further 17  
investigation of this subzone is anticipated. 18

#### Threatened and Endangered Species 19

Several species of concern may be present within portions of Zone C. Table 8.2 lists those species 20  
that have been historically or recently identified at or near NAVBASE. Risk to these species from 21  
observed contamination will be addressed as appropriate. 22

Table 8.2  
Federal and State Listed Threatened, Endangered, and Candidate Species  
That Occur or Potentially Occur on NAVBASE

Species		Status		
Common Name	Scientific Name	Residence Status	USF&WS	SCWMRD
<b>Reptiles and Amphibians</b>				
American Alligator	<i>Alligator mississippiensis</i>	PR	T/SA	T/SA
Flatwoods Salamander	<i>Ambystoma cingulatum</i>	UR	C-2	SC
Eastern Tiger Salamander	<i>Ambystoma tigrinum tigrinum</i>	PR	—	SC
Broad-Striped Dwarf Siren	<i>Pseudobranchius striatus striatus</i>	PR	—	SC
Crawfish Frog	<i>Rana areolata</i>	PR	—	SC
Loggerhead Turtle	<i>Caretta caretta</i>	PM	T	T
Kemp's Ridley Sea Turtle	<i>Lepidochelys kempi</i>	PM	E	E
Island Glass Lizard	<i>Ophisaurus compressus</i>	UR	SR	SR
<b>Birds</b>				
Brown Pelican	<i>Pelecanus occidentalis</i>	LM	—	SC
Wood Stork	<i>Mycteria americana</i>	LM	E	E
Osprey	<i>Pandion haliaetus</i>	CR	—	SC
American Swallow-Tailed Kite	<i>Elanoides forficatus forficatus</i>	PM	SR	E
Bachman's Sparrow	<i>Aimophila aestivalis</i>	UR	SR	SR
Red-Cockaded Woodpecker	<i>Picoides borealis</i>	UR	E	E
Bachman's Warbler	<i>Vermivora bachmanii</i>	UR	E	E
Bald Eagle	<i>Haliaeetus leucocephalus</i>	LM	E	E
Arctic Peregrine Falcon	<i>Falco peregrinus tundrius</i>	PM	T	T
Piping Plover	<i>Charadrius melodus</i>	PM	T	T
Least Tern	<i>Sterna antillarum</i>	CR	—	T
Least Tern Breeding Colony		CR	—	SC
Wading Bird Breeding Colony		CR <sup>a</sup>	—	SC
<b>Mammals</b>				
Black Bear	<i>Ursus americanus</i>	UM	—	SC
West Indian Manatee	<i>Trichechus manatus</i>	PM	E	E
<b>Fish</b>				
Shortnose Sturgeon	<i>Acipenser brevirostrum</i>	LM	E	E
<b>Plants</b>				
Canby's Dropwort	<i>Oxpolis canbyi</i>	UR	E	E
Pondberry	<i>Lindera melissifolia</i>	UR	E	E
Incised Groovebur	<i>Agrimonia incisa</i>	UR	C-2	NC
Sea-beach Pigweed	<i>Amaranthus pumilus</i>	UR	SR	NC
Cypress Knee Sedge	<i>Carex decomposita</i>	UR	SR	—

**Table 8.2**  
**Federal and State Listed Threatened, Endangered, and Candidate Species**  
**That Occur or Potentially Occur on NAVBASE**

Species		Status		
Common Name	Scientific Name	Residence Status	USF&WS	SCWMRD
<b>Plants (continued)</b>				
Chaff-Seed	<i>Schwalbea americana</i>	UR	SR	NC
Whisk Fern	<i>Psilotum nudum</i>	UR	—	SL
Climbing Fern	<i>Lygodium palmatum</i>	UR	—	SL
Piedmont Flatsedge	<i>Cyperus tetragonus</i>	PR	—	SL
Baldwin Nutrush	<i>Scleria baldwinii</i>	UR	—	SL
Nodding Pogonia	<i>Triphora trianthophora</i>	UR	—	SL
Savannah Milkweed	<i>Asclepias pedicellata</i>	UR	—	RC
Venus' Fly-Trap	<i>Dionaea muscipula</i>	UR	—	RC
Sweet Pinesap	<i>Monotropsis odorata</i>	UR	—	RC
Climbing Fetter-bush	<i>Pieris phillyreifolia</i>	UR	—	SL
Sea Purslane	<i>Trianthema portulacastrum</i>	CR	—	SC

**Notes:**

a	=	Wading bird colony has been a confirmed resident at the base, but was not present during field studies in April 1994.
CR	=	Confirmed resident
LR	=	Likely resident
PR	=	Possible resident
UR	=	Unlikely resident
LM	=	Likely migrant or occasional visitor
PM	=	Possibly migrant or occasional visitor
UM	=	Unlikely migrant or occasional visitor
SC	=	Of concern, state
SR	=	Status review
E	=	Endangered
T	=	Threatened
SL	=	State listed
RC	=	Of concern, regional
NC	=	Of concern, national
C-2	=	Candidate species for federal listing, Category 2
T/SA	=	Threatened due to similarity of appearance
USF&WS	=	U.S. Fish and Wildlife Service
SCWMRD	=	South Carolina Wildlife and Marine Resources Department

**Source:** Final Environmental Impact Statement for Disposal and Reuse of the Charleston Naval Base (E & E, June 1995)

### **8.3 Conceptual Model**

Figure 8.3 presents a conceptual model of the potential contaminant pathways from source to ecological receptors for Zone C subzones. For this assessment, exposure routes directly related to soil pathways are evaluated for Subzones C-1 and C-2. Subzone C-1, located upgradient of Noisette Creek, was also preliminarily characterized for sediment and water exposure routes to determine the need for additional assessment during the Zone J RFI study. Direct impacts to terrestrial plants are not included in this assessment but transfer mechanisms are considered in food chain transfer analyses. Information related to specific contaminant toxic mechanisms to vegetation are also discussed.

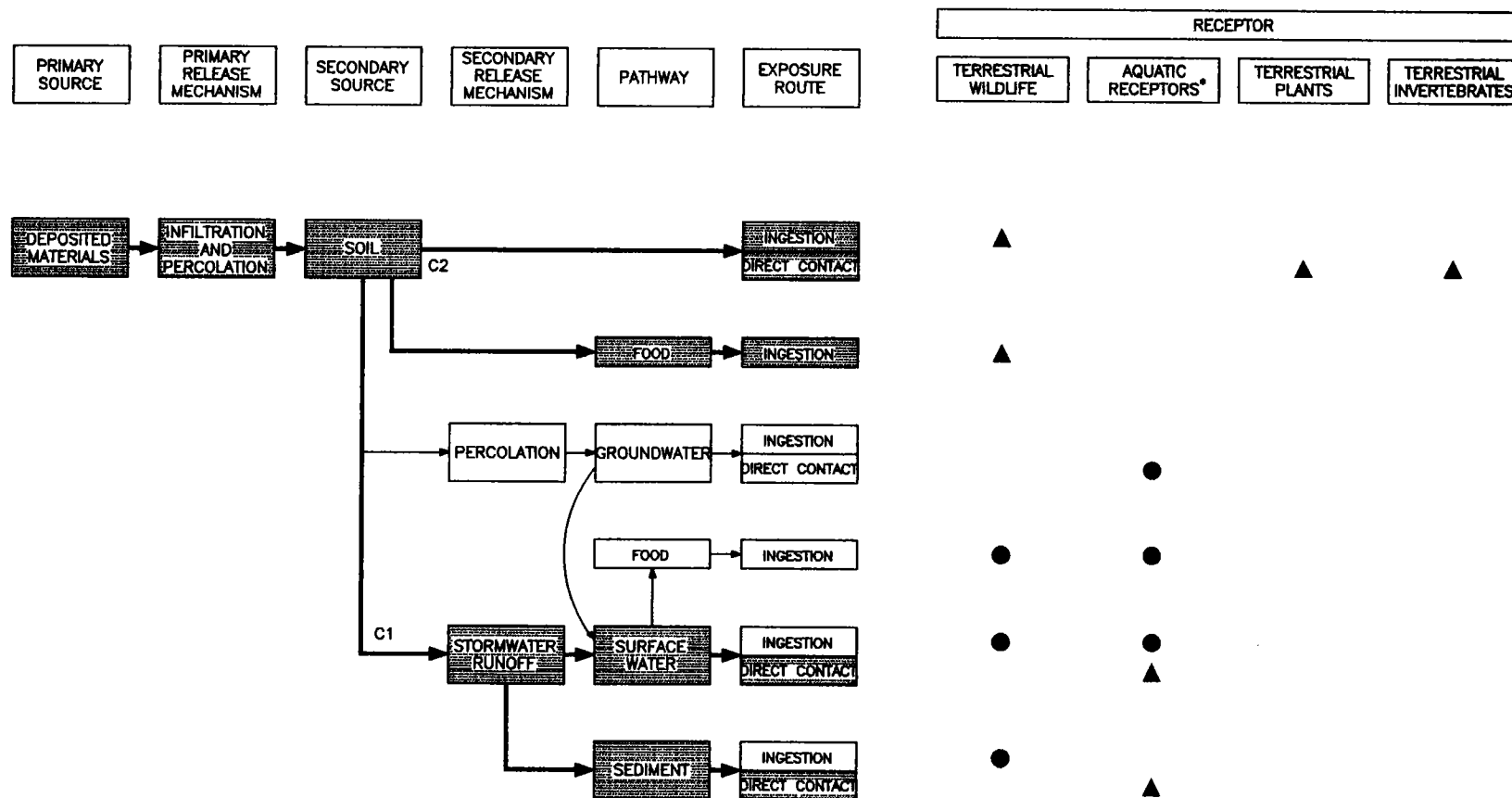
### **8.4 Selection of Ecological Chemicals of Potential Concern**

Section 10 of this report discusses past activities at Zone C SWMUs and AOCs associated with the designated ecological subzones that may have impacted the surrounding ecosystem (see Table 8.1). COCs resulting from these activities have been identified and quantified according to USEPA methods and protocols for analyses of soil, surface water, and sediment. For the assessment of ecological risk, it was necessary to identify ecological contaminants of potential concern (ECPCs) using the following criteria. To evaluate impacts representative of both isolated hot spots as well as overall concentrations detected across each subzone, both the maximum and mean concentrations for each matrix are presented for comparison to the most appropriate screening value, UTL, or effect level (EL).

#### **Surface Soil**

In subzone surface soil, inorganic parameters with a mean concentration exceeding the UTL of background were identified as ECPCs. Since organic constituents do not occur naturally in surface soil, all detected organic parameters were identified as ECPCs. Only the results from surficial soil (0 to 1 foot bgs) are addressed. It is presumed, even considering root development in the lower strata, that most biological effects will be limited to the upper zone.





AQUATIC RECEPTORS - INVERTEBRATES, PLANTS, ALGAE, AMPHIBIANS, AND FISH  
 NOTE: SHADED BOXES, BOLD ARROWS, AND TRIANGLES INDICATE SELECTED PATHWAY



ZONE C  
 RCRA FACILITY  
 INVESTIGATION REPORT  
 NAVAL BASE CHARLESTON  
 CHARLESTON, S.C.

FIGURE 8.3  
 CONTAMINANT PATHWAY MODEL FOR  
 ECOLOGICAL RECEPTORS

DWG DATE: 09/25/97 | DWG NAME: 29ZCCPMF

## **Sediment**

In subzone sediment, analytes were selected as ECPCs if the mean detected concentration either: (1) exceeded the USEPA Region IV Sediment Screening Value, (2) exceeded the most conservative effects level found in literature, or (3) if neither of these benchmarks was available. To estimate both point-specific and subzone-wide risk potentials, the maximum and mean concentrations for sediment inorganic constituents were divided by the available benchmark to produce a respective Hazard Quotient (Max HQ or Mean HQ). HQs are a common screening method developed by Region III USEPA for predicting ecological risk. HQs greater than 1 are considered to demonstrate a potential risk. Values greater than 10 are considered to be of moderately high potential risk and above 100, extreme risk.

## **Surface Water**

In subzone surface water, analytes were selected as ECPCs if the mean concentration detected either: (1) exceeded the South Carolina or USEPA water quality criteria, (2) exceeded the USEPA Region IV Surface Water Screening Value (November 1995), or (3) if neither of these benchmarks was available.

Calcium, magnesium, potassium, and sodium were not included in this assessment process because they are naturally occurring nutrients.

Although zone-specific groundwater has been monitored, water table depth (approximately 5 feet bgs) within Zone C precludes assessing ecological impacts from this medium immediately within the zone perimeter. Wetland areas in Zone C are either tidally influenced (such as those in C-1) or associated with storm water runoff (C-2) and not considered significantly affected by groundwater discharge. See Section 10 for further information on groundwater-to-surface water cross-media transport.

### **Subzone C-1**

For the ERA of Subzone C-1, the analytical results from the three surface soil samples NBCC044SB006, -025, and -026 and eight Subzone C-1 sediment and surface water samples (NBCC/044-0011 through -0017, and -0019) were considered. Results for Zone C samples collected in Noisette Creek (Zone J) are preliminarily assessed in Section 10, but with the limited Zone C samples, it is considered more appropriate to assess ecological risk to the creek during the Zone J RFI in which additional sampling will be conducted both up and downgradient of Zone C's SWMU 44 outfall.

### **Subzone C-2**

For the ERA of Subzone C-2, seven surface soil samples (NBCC/512-SB001 through SB007) were considered. One sample (SB003) was analyzed for Appendix IX parameters, including organophosphorous pesticides, herbicides, and dioxins. Although two additional soil samples were collected at AOC 512 (SB008 and SB009) and analyzed for semivolatile constituents, no SVOCs were present above the laboratory's detection limits. Furthermore, no sediment or surface water was present for analysis at Subzone C-2. Tables 8.3 (a, b, and c) and 8.4 (a and b) present the ECPCs identified for Subzones C-1 and C-2, respectively.

**Table 8.3a**  
**Subzone C-1**  
**Inorganic Constituents in Surface Soil (mg/kg)**

Inorganics	Detections (N=3)	Range of Concentrations	Mean Concentration	UTL of Background <sup>a</sup>	ECPC
Aluminum	3	2,800 - 36,600	18,966.67	9,990	Yes
Arsenic	3	2.8 - 103	44.13	14.2	Yes
Barium	3	6.7 - 55.4	36.17	77.2	No
Beryllium	3	0.16 - 2.0	1.35	NA	Yes
Cadmium	2	0.51 - 3.6	2.06	ND	Yes
Chromium	3	7.3 - 54.3	36.17	26.4	Yes
Cobalt	3	5.6 - 13.6	9.27	3.22	Yes
Copper	3	4.5 - 122	56.80	34.7	Yes
Iron	3	3,520 - 99,500	44,973.33	NA	Yes
Lead	3	26.1 - 64.2	42.70	330	No
Manganese	3	96.3 - 408	234.43	92.5	No
Mercury	2	0.15 - 0.53	0.34	0.24	Yes
Nickel	3	14.0 - 43.4	31.43	12.3	Yes
Selenium	2	0.72 - 8.8	4.76	1.44	Yes
Thallium	1	2.4	2.4	ND	Yes
Vanadium	3	7.1 - 68.2	39.10	23.4	Yes
Zinc	3	65.5 - 279	155.83	159	No

**Notes:**

- N = Total number of surface soil samples collected at the subzone.
- a = See Section 5 for Upper Tolerance Limit determination.
- ECPC = Ecological Chemical of Potential Concern. Mean Concentration > UTL of Background.
- NA = Data are not available.
- ND = Not Detected



**Table 8.3b**  
**Subzone C-1**  
**Inorganic Constituents in Sediment (mg/kg)**

Inorganic Elements	Detections (N=7)	Range of Concentrations	Mean Concentration	Effects Level <sup>a</sup> (EL)	Max HQ	Mean HQ	ECPC
Aluminum	7	3,500 - 10,900	6,372.86	NA	-	-	Yes
Antimony	3	0.53 - 1.20	0.90	12	0.1	0.08	No
Arsenic	7	4.0 - 69.20	40.26	7.24	9.3	5.56	Yes
Barium	7	12.0 - 70.7	35.50	NA	-	-	Yes
Beryllium	1	0.65	0.65	NA	-	-	Yes
Cadmium	5	0.04 - 0.84	0.42	1.0	0.8	0.42	No
Chromium	7	8.5 - 42.1	20.10	52.3	0.8	0.38	No
Cobalt	7	1.6 - 11.6	4.60	NA	-	-	Yes
Copper	7	7.2 - 75.3	33.77	18.7	4.0	1.81	Yes
Iron	7	5,160 - 93,700	35,227.14	NA	-	-	Yes
Lead	7	11.2 - 43.7	32.07	30.2	1.4	1.06	Yes
Manganese	6	36.9 - 96.1	66.67	NA	-	-	Yes
Mercury	6	0.17 - 1.6	0.59	0.13	12.3	4.54	Yes
Nickel	7	3.8 - 26.7	10.54	15.9	1.7	0.66	No
Selenium	5	0.83 - 9.3	5.45	NA	-	-	Yes
Thallium	4	1.9 - 4.6	2.83	NA	-	-	Yes
Vanadium	7	8.1 - 33.5	21.50	NA	-	-	Yes
Zinc	7	31.2 - 125.0	69.21	124	1.0	0.56	No

**Notes:**

- a = Effects Level (EL) represents USEPA Region IV (1995) Sediment Screening Values (SSV).
- Max HQ = Hazard Quotient calculated by dividing maximum concentration by the effect level.
- Mean HQ = Hazard Quotient calculated by dividing mean concentration by the effect level.
- ECPC = Ecological Chemical of Potential Concern. Parameter with mean concentration > EL or EL=NA.
- NA = Data are not available.

**Table 8.3c**  
**Subzone C-1**  
**Inorganic Constituents in Surface Water (µg/L)**

Inorganic Elements	Detections (N=8)	Range of Concentrations	Mean Concentrations	Effects Level <sup>a</sup> (EL)	Max HQ	Mean HQ	ECPC
Aluminum	6	188.0 - 16,400	5,169	87	189	59.4	Yes
Antimony	4	2.4 - 5.2	3.28	160	0.03	0.02	No
Arsenic	5	6.2 - 144.0	35.42	190	0.7	0.19	No
Barium	8	12.6 - 75.2	24.51	NA	-	-	Yes
Beryllium	2	3.7 - 5.2	4.45	0.53	9.8	8.4	Yes
Cadmium	1	0.70	0.70	0.66	1.1	1.1	Yes
Chromium (III)	8	1.6 - 52.4	10.24	117.32	0.4	0.09	No
Chromium (VI)	8	1.6 - 52.4	10.24	11	4.8	0.93	No
Cobalt	6	0.93 - 71.0	23.02	NA	-	-	Yes
Copper	7	4.9 - 92.5	24.41	6.54	14.1	3.7	Yes
Iron	8	578.0 - 85,900	16,954.50	1,000	85.9	17	Yes
Lead	5	3.8 - 9.2	5.8	1.32	6.9	4.4	Yes
Manganese	8	64.3 - 2,110.0	595.36	NA	-	-	Yes
Nickel	7	2.5 - 107.0	35.14	87.71	1.2	0.4	No
Selenium	4	4.6 - 10.4	7.40	5	2.1	1.5	Yes
Vanadium	8	0.71 - 6.9	3.28	NA	-	-	Yes
Zinc	8	15.1 - 202.0	69.16	58.91	3.4	1.2	Yes

**Notes:**

Reported concentrations of hardness-dependent compounds have not been adjusted for site-specific conditions.

N = Total number of surface water samples collected in subzone.

a = Effects Level (EL) represents USEPA Region IV (1995) Freshwater Chronic Screening Value (USEPA, 1995).

Max HQ = Hazard Quotient calculated by dividing maximum concentration by the effect level.

Mean HQ = Hazard Quotient calculated by dividing mean concentration by the effect level.

- = HQ not calculable

ECPC = Ecological Chemical of Potential Concern. Parameter with mean concentration > EL or EL = NA.

NA = Data are not available.

Table 8.4a  
Subzone C-2  
Organic ECPCs in Surface Soil (µg/kg)

Compound Name	Number of Detections	Range of Concentrations	Mean Concentration
<b>Semivolatile Organic Compounds (N = 7)</b>			
Benzo(a)anthracene	7	45 - 140	84
Benzo(a)pyrene	6	60 - 120	85.67
Benzo(b)fluoranthene	7	110 - 270	191.43
Benzo(g,h,i)perylene	1	66	66
Benzo(k)fluoranthene	7	95 - 300	176.43
Chrysene	7	58 - 170	94
Fluoranthene	7	76 - 240	152.29
Indeno(123-cd)pyrene	1	60	60
Phenanthrene	6	49 - 120	82.50
Pyrene	7	52 - 210	98.71
<b>Pesticides/PCBs (N = 7)</b>			
Aldrin	1	1.10	1.10
Aroclor 1254	1	60	60
beta-BHC	3	1.6 - 8.4	5.57
Chlordane	2	3.1 - 4.2	3.65
4,4'-DDD	2	4.1 - 37	20.55
4,4'-DDE	5	4.3 - 140	34.48
4,4'-DDT	3	7.6 - 55	27.87
Dieldrin	1	2	2
Endosulfan	1	2.4	2.4
Endrin aldehyde	4	1.6 - 13	5.13
Methoxychlor	1	4.3	4.3
Methyl parathion	1	4.7	4.7

Table 8.4a  
Subzone C-2  
Organic ECPCs in Surface Soil (µg/kg)

Compound Name	Number of Detections	Range of Concentrations	Mean Concentration
<b>Organophosphorous Pesticide (N = 1)</b>			
Disulfoton	1	5.2	5.2
Sulfotepp	1	4.5	4.5
<b>Herbicide (N = 1)</b>			
2,4,5-T	1	8.5	8.5
<b>Dioxins (N=1, ng/kg)</b>			
Total Hepta-Dioxins	1	77.57	77.57
Total Hexa-Dioxins	1	12.54	12.54
Total Hexa-Furans	1	13.04	13.04
Total Penta-Furans	1	8.0	8.0
1234678-HxCDF	1	31.62	31.62
123478-HxCDF	1	3.13	3.13
123678-HxCDF	1	1.13	1.13
234678-HxCDF	1	1.24	1.24
OCDD	1	186.12	186.12
OCDF	1	9.78	9.78

**Notes:**

ng/kg = nanograms per kilogram

N = Number of samples collected

ECPC = Ecological Chemical of Potential Concern; all organics are considered ECPCs.



**Table 8.4b**  
**Subzone C-2**  
**Inorganic Constituents in Surface Soil (mg/kg)**

Inorganic Elements	Detections (N=6)	Range of Concentrations	Mean Concentration	UTL of Background <sup>a</sup>	ECPC
Aluminum	6	3,960 - 10,600	6,842.86	9,990	No
Arsenic	6	2.2 - 8.2	4.74	14.2	No
Barium	6	14.10 - 40.7	22.74	77.2	No
Beryllium	4	0.27 - 0.44	0.34	NA	Yes
Cadmium	5	0.21 - 0.77	0.48	0.65	No
Chromium	6	9.3 - 21.7	13.82	26.4	No
Cobalt	6	1 - 4.4	2.58	3.22	No
Copper	6	10.7 - 39	23.38	34.7	No
Iron	6	5,570 - 11,800	8,640	NA	Yes
Lead	6	21.7 - 76.1	46.22	330	No
Manganese	6	46 - 280	173.52	92.5	Yes
Mercury	6	0.1 - 0.35	0.19	0.24	No
Nickel	6	2 - 9.5	6.22	12.3	No
Selenium	6	0.59 - 1.0	0.75	1.44	No
Tin	6	1.3 - 1.9	1.65	2.95	No
Vanadium	6	13.9 - 24.5	17.60	23.4	No
Zinc	6	35.3 - 124	76.73	159	No

**Notes:**

a = See Section 5 for Upper Tolerance Limit determination.  
ECPC = Ecological Chemical of Potential Concern. Parameter with mean concentration > UTL or EL = Not Valid.  
NA = Not Available  
ND = Not Detected

## **8.5 Contaminant Fate and Transport**

Surface soil across Zone C consists of fine-to medium-grained sand with silt and some clay. This soil type is typically low in organic material with medium permeability. These factors most likely limit development of a microbial community, thereby reducing the likelihood of microbial decomposition of sorbed organic contaminants. These contaminants will therefore be expected to either remain in the soil to undergo degradation or migrate downward.

In addition, contaminants sorbed to surface soil could be transported via air or surface water runoff. However, both of these pathways are unlikely as major routes. Contaminants are not expected to spread far via surface runoff due to the substrate's permeable nature. The physical adsorption of contaminants to soil particles and available organic material also limits horizontal migration. Migration via air pathways could be significant only as it relates to dispersal of upper soil layer particles during high winds typical of coastal areas. Because sand particles are relatively large and heavy, extended migration through this route is not expected. Fate and transport issues are discussed in detail in Section 6.

## **8.6 Exposure Pathways and Assessment**

Once the ECPCs were identified for each subzone in Zone C, an assessment of the potential exposure pathways was performed. Because of the lack of an identified migration pathway from any known contaminant source, exposure routes associated with Subzone C-3 were not evaluated. If the potential exposure of a Zone C ECPC to an ecological receptor in either Subzone C-1 or C-2 was indicated, the potential risk to that receptor (or group of receptors) was then evaluated. Based on the habitat types observed in each Zone C subzone, the exposure pathways to the following potential receptors were identified: infaunal invertebrates (worms and insects living within the soil), terrestrial wildlife (birds/mammals), vegetation, and aquatic wildlife.

### ***Infaunal Invertebrates***

The primary exposure pathway evaluated for infaunal invertebrates will be via direct contact with surface soil. An assessment endpoint of a well-balanced soil infaunal community will be qualitatively measured by comparing literature data on toxic effects to actual soil concentrations.

### ***Terrestrial Wildlife***

For terrestrial wildlife species, exposure would include direct dermal contact, ingestion of soil particles, and food-chain transfer. Small mammals could contact contaminated soil if the area is a migratory corridor or if animals burrow into it. Contact time (exposure) will be limited when animals are crossing the area, but could be lengthy if burrows are established. Dermal contact by small reptiles and amphibians would be similar to that for mammals. For insect populations, direct exposure to ground-dwelling species could provide a link for contaminant transfer to higher-level predators.

The assessment endpoint selected for terrestrial wildlife is the maintenance of well-balanced terrestrial wildlife populations and communities. As a measure of the assessment endpoint selected, EnSafe used results of laboratory toxicity studies in literature that relate the oral dose of a contaminant to adverse response to growth, reproduction, or survival. Selected measurement endpoint species include: Eastern cottontail rabbit (*Sylvilagus floridanus*), short-tailed shrew (*Blarina brevicauda*), and American robin (*Turdus migratorius*). All of these species (or an equivalent) are likely to occur within the designated subzones in Zone C.

To assess biotransfer of contaminants along food chains, the total potential dietary exposure (PDE) has been modeled for representative terrestrial wildlife species within Subzones C-1 and C-2. PDEs are calculated based on predicted concentrations of the ECPCs in food items that the species would consume, the amount of soil it would ingest, the relative amount of different food items in its diet, body weight, and food ingestion rate (Table 8.5). The concentrations of ECPCs in food

items are estimated based upon literature reported bioaccumulation factors (BAFs), which are a ratio of the ECPC concentration in dietary items to the concentration in surface soil. The BAFs reported for avian and mammalian species are reported ratios of ECPCs in the tissue of the animals to the concentrations of ECPCs in their diets.

**Table 8.5**  
**Wildlife Contaminant Exposure Model for Surface Soil**

$$\begin{aligned} \text{Food Contaminant Concentration (mg/kg)} &= \text{BAF}^1 \times \text{Soil Contaminant Concentration (mg/kg)} \\ \\ \text{Soil Exposure [SE](mg/kg)} &= (\% \text{ diet soil}) \times \text{Soil Contaminant Concentration (mg/kg)} \\ \\ \text{PDE (mg contaminant/kg BW/day)} &= \frac{[P_1 \times T_1 + P_2 \times T_2 + \dots P_n \times T_n + \text{SE}] \times \text{IR}_{\text{diet}} \times \text{SFF}}{\text{BW}} \end{aligned}$$

where:

$P_n$  = percent of diet composed of food item N  
 $T_n$  = tissue concentration in food item N (FCC in mg/kg)  
 $\text{IR}_{\text{diet}}$  = food ingestion rate of receptor (kg of food per day)  
 SFF = site foraging factor (cannot exceed 1)  
 BW = receptor body weight (kg)  
 1 = BAF from Table 8-7  
 PDE = Potential Dietary Exposure

The site foraging factor (SFF) allows the frequency of feeding in the area to be considered by estimating it relative to the receptor's feeding range and by considering the fraction of the year the receptor would be exposed to site contaminants.



### ***Vegetation***

Woody and herbaceous vegetation in Subzones C-1 and C-2 could likely incorporate certain detected constituents (primarily metals) through processes such as uptake/accumulation, translocation, adhesion, or biotransformation. These plant-borne constituents could also be ingested by terrestrial herbivores.

### ***Aquatic Wildlife***

The primary exposure pathway evaluated for aquatic wildlife species in Subzone C-1 (Noisette Creek tributary), is contact or interface with water and sediment. An assessment endpoint, evaluating the aquatic community health, has been selected with a measurement endpoint that predicts chronic effects to aquatic community species. The complete assessment of Noisette Creek is to be conducted during the more comprehensive Zone J RFI, which will incorporate all pertinent information obtained during the Zone C ERA.

## **8.7 Ecological Effects Assessment**

In addition to determining the exposure potentials associated with each site, the effects of certain ECPCs upon selected receptors was examined. Based on the known characteristics of these potential contaminants or "stressors," their associated effects can be better predicted.

### **Stressor Characteristics**

#### ***Inorganics***

In general, heavy metals adversely affect survival, growth, reproduction, development, and metabolism of both terrestrial and aquatic invertebrate species, but effects are substantially modified by physical, chemical, and biological variables. Pascoe et al. (1994) observed that, in general, bioavailability of metals in soil to small mammals was limited. Their study also suggests that metal intake for higher trophic species may be similarly limited. Most heavy metals do not

biomagnify. In contact tests with terrestrial earthworms the order of toxicity for heavy metals from most toxic to least toxic was copper > zinc > nickel = cadmium > lead.

Arsenic, an ECPC in sediments at Subzone C-1, naturally occurs and, with respect to cycling in the environment, is constantly changing. Many inorganic arsenicals are known teratogens and are more toxic than organic arsenicals (Eisler, 1988). Soil biota appear to be capable of tolerating and metabolizing relatively high concentrations (microbiota to 1,600 ppm) of arsenic (Wang et al., 1984). But adverse effects to aquatic organisms have been reported at concentrations of 19 to 48 ppb in water. Arsenic in soil does not appear to magnify along the aquatic food chain.

Cadmium, an ECPC in Subzone C-1 soils and surface water, is a relatively rare heavy metal. It is a known teratogen and carcinogen and probably a mutagen, and has been implicated as the cause of severe deleterious effects on fish and wildlife (Eisler, 1985). Birds and mammals are comparatively resistant to the biocidal properties of cadmium. Freshwater organisms appear to be the most susceptible group to cadmium toxicity, which is modified significantly by water hardness. Adsorption and desorption processes are likely to be major factors in controlling cadmium concentrations in natural waters. Adsorption and desorption rates of cadmium are rapid on mud solids and particles of clay, silica, humic material, and other naturally occurring solids.

Chromium is an ECPC in the surface waters at Subzone C-1. Hexavalent chromium (Cr VI) produces more adverse effects to biota than the trivalent phase does. In clayey sediments, trivalent chromium dominates and benthic invertebrate bioaccumulation is limited (Neff et al., 1978).

Copper, an ECPC in Subzone C-1 soil, sediment, and surface water, is an essential micronutrient, and therefore, it is readily accumulated by aquatic organisms. It is a broad-spectrum biocide and may be associated with both acute and chronic toxicity.

Lead, an ECPC in Subzone C-1 sediments and surface water, is primarily found in association with iron and manganese hydroxides and may also form associations with clays and organic matter. Under oxidizing conditions, lead tends to remain tightly bound to sediments, but is released into the water column under reducing conditions. Lead may accumulate to relatively high concentrations in aquatic biota.

Mercury, an ECPC in Subzone C-1 sediments, is a known mutagen, teratogen, and carcinogen. It adversely affects reproduction, growth, development, motor coordination, and metabolism. Mercury has a high potential for bioaccumulation and biomagnification and is slow to depurate. Organomercury compounds produce more adverse effects than inorganic mercury compounds. Inorganic mercury can be biologically transformed to organic mercury compounds.

Zinc is an ECPC in Subzone C-1 surface water. In water, zinc speciates into the toxic aquo ion, other dissolved chemical species, and various inorganic and organic complexes. It is readily transported. Most zinc introduced into aquatic environments is eventually partitioned into the sediments. Reduced conditions enhance zinc's bioavailability.

No information was available on the toxicological effects associated with other inorganic ECPCs for soil, sediment, or surface water.

### ***Organics***

Little information exists on the toxic effects from VOCs. Primarily, the only information available are effects studies related to human health from inhalation of specific compounds by laboratory animals.

PAHs, detected in Subzone C-2 surface soils, vary by molecular weight. With increasing molecular weight, aqueous solubility decreases and the octanol-water partition coefficient ( $\log K_{ow}$ )

increases, suggesting increased solubility in fats, a decrease in resistance to oxidation and reduction, and a decrease in vapor pressure (Eisler, 1987a). Accordingly, PAHs of different molecular weight vary substantially in their behavior and distribution in the environment and in their biological effects. In water, PAHs either evaporate, disperse into the water column, become incorporated into sediments, or undergo degradative processes such as photooxidation, chemical oxidation, and biological transformation by bacteria and animals (Neff, 1979). PAHs show little tendency to biomagnify in food chains because most are rapidly metabolized (Eisler, 1987a). Very little information is available on adverse effects to a food chain as a result of soil PAH contamination.

Organochlorine pesticides, an ECPC in Subzone C-2 soils, have been used extensively in the United States since the 1940s. They appear to be ubiquitous in the environment, being found in surface water, sediment, and biological tissues across the nation. They are readily absorbed by warm-blooded species and degradatory products are frequently more toxic than the parent form. Food chain biomagnification is usually low, except in some marine mammals. In soil invertebrates, organochlorine pesticides can accumulate to concentrations higher than those in the surrounding soil, and residues may in turn be ingested by birds and other animals feeding on earthworms (Beyer and Gish, 1980). Most environmental effects studies have been directed at mammals and birds.

PCBs, classified as ECPCs in Subzone C-2 soils, are distributed worldwide with measurable concentrations recorded in fishery and wildlife resources from numerous locations (Eisler, 1986). They are known to bioaccumulate and to biomagnify within the food chain and to elicit biological effects such as death, birth defects, tumors, and a wasting syndrome. In terrestrial environments, PCBs are rapidly metabolized from the soil into the terrestrial food chain (McKee, 1992). Subsoil-dwelling organisms may directly absorb PCBs and may transfer through the food chain to species.

Dioxins (an ECPC in Subzone C-2 surface soil) are trace compounds in some commercial herbicides and chlorophenols (Eisler, 1986). The most toxic and most extensively studied dioxin is 2,3,7,8-TCDD. Laboratory studies with birds, mammals, aquatic organisms, and other species have demonstrated that exposure to 2,3,7,8-TCDD can result in acute and delayed mortality as well as mutagenic and reproductive effects. In soil, microbial decomposition of TCDD is slow (Ramel, 1978) and uptake by vegetation is considered negligible (Blair, 1973).

## **Assessment of Potential Receptors**

### ***Infaunal Invertebrates***

Predicted potential adverse ecological effects to soil invertebrates from identified ECPCs in Zone C are based on effects information in available literature. Because soil MCLs are unavailable for effects levels, studies are used for comparative qualitative assessments only.

### ***Terrestrial Wildlife***

Potential adverse effects associated with the identified ECPCs to bird and mammal species are based on food uptake potential. Available toxicity reference values (TRVs) were determined for each measurement endpoint species selected. The TRV relates the dose of a respective ECPC in an oral exposure with an adverse effect. The lethal TRV has been determined to be one-fifth of the lowest reported LD<sub>50</sub> value (concentration of a contaminant at which half of the exposed test population die) for the most closely related test species (Table 8.6). One fifth of an oral LD<sub>50</sub> value is considered to be protective of lethal effects for 99.9 % of individuals in a test population (USEPA, 1986). It is assumed that this level of risk to individuals within terrestrial wildlife populations across Zone C is acceptable.

A sublethal TRV is also identified, representing a threshold for sublethal effects. Sublethal effects are defined as those that impair or prevent reproduction, growth, or survival. Sublethal TRVs are therefore based on the lowest observed adverse effect level (LOAEL) for the most closely related



**Table 8.6**  
**Chemical Effects Studies on Terrestrial Infaunal Invertebrates**

Study	Organisms	Measured Parameter	Effects Level	Measured Response
Parmelee et al. (1993)	nematode/microarthropods	Copper	200 mg/kg	Significant decline in numbers
Neuhauser et al. (1986)	earthworm <i>Eisenia foetida</i>	Copper salts	643 mg/kg	LC <sub>50</sub>
		Zinc salts	662 mg/kg	LC <sub>50</sub>
		Nickel salts	757 mg/kg	LC <sub>50</sub>
		Cadmium salts	1,843 mg/kg	LC <sub>50</sub>
		Lead salts	6,000 mg/kg	LC <sub>50</sub>
		4-Nitrophenol	38 mg/kg	LC <sub>50</sub>
		Fluorene	173 mg/kg	LC <sub>50</sub>
		Phenol	401 mg/kg	LC <sub>50</sub>
Roberts & Dorough (1984)	<i>Eisenia foetida</i>	Cadmium chloride	10 - 100 µg/cm <sup>2</sup>	LC <sub>50</sub>
		Copper sulfate	10 - 100 µg/cm <sup>2</sup>	LC <sub>50</sub>
		Lead nitrate	10 - 100 µg/cm <sup>2</sup>	LC <sub>50</sub>
Malecki et al. (1982) <sup>a</sup>	<i>Eisenia foetida</i>	Cadmium	250 mg/kg	Growth difference to control
		Nickel	440 mg/kg	
		Copper	1,320 mg/kg	
		Zinc	2,800 mg/kg	
		Lead	21,600 mg/kg	
Strait (1984)	Mite <i>Platynothrus peltifer</i>	Copper	200 mg/kg	Population decrease
van Straalen et al. (1989)	Mites	Cadmium	> 128 mg/kg	Mortality

Table 8.6  
 Chemical Effects Studies on Terrestrial Infaunal Invertebrates

Study	Organisms	Measured Parameter	Effects Level	Measured Response
McKee (1992)	Terrestrial epigeic <sup>b</sup> Invertebrates	PCBs	120,000 mg/kg	No community structure effects
Callahan, et al. (1991)	earthworms <i>L. terrestris</i>	DDT	400 µg/kg	No detectable concentration in tissue from soil concentrations
		DDD	700 µg/kg	
		DDE	200 µg/kg	
Menzie et al. (1992)	<i>Eisenia foetida</i>	DDT	1,000 [4,000] <sup>a</sup> µg/kg	Survival; no effect for LC <sub>50</sub> test
		DDD	1,000 [12,000] <sup>a</sup> µg/kg	
		DDE	1,000 [2,000] <sup>a</sup> µg/kg	
Miller et al. (1985)	Earthworm	Copper	644 mg/kg	EC <sub>50</sub>
		Zinc	628 mg/kg	EC <sub>50</sub>
	Microtox (15 min.)	Copper	0.28 - 0.42 mg/kg	Photo reduction
		Zinc	1.6 mg/kg	Photo reduction
Paine et al. (1993)	Crickets <i>Acheta domesticus</i>	PCBs	1,200 mg/kg	LC <sub>50</sub>
Reinecke & Nash (1984)	Earthworm	Dioxin	< 5 mg/kg	No mortality
	<i>Allolobophora caliginosa</i>			
	<i>Lumbricus rubellus</i>			
Ma (1984)	<i>Lumbricus rubellus</i>		> 10 mg/kg	Lethality
		Copper	100 - 150 mg/kg	Cocoon production decrease
		Copper	300 mg/kg	Mortality
Beyer et al. (1985)	<i>Eisenia foetida</i>	Methyl Mercury	25 mg/kg	100% mortality
			5 mg/kg	21% mortality

**Table 8.6**  
**Chemical Effects Studies on Terrestrial Infaunal Invertebrates**

Study	Organisms	Measured Parameter	Effects Level	Measured Response
Abbasi and Soni (1983)	Earthworm	Inorganic Mercury	0.79 mg/kg	50% mortality
	<i>Octochaetus pattoni</i>		5 mg/kg	100% mortality
Rhett et al. (1988)	<i>Eisenia foetida</i>	PCBs	240 mg/kg	LC <sub>50</sub>
Nielson (1951)	earthworms	Copper	150 mg/kg	Population reduced by 0.5
			260 mg/kg	Population eliminated
Van Rhee (1967)	earthworms	Copper	85 mg/kg	Gradual decline of population
Ma (1982)	<i>Lumbricus rubellus</i>	Copper chloride	1,000 mg/kg	6-wk LC <sub>50</sub>

**Notes:**

- a = Growth effects levels are an average of at least five of six compounds: metal acetate; metal carbonate; metal chloride; metal nitrate; metal oxide, metal sulfate
- b = Aboveground species include Carabidae, Entobeyidae, Formicidae, Gryllidae and Staphylinidae.
- c = Average soil concentration levels [maximum values].

test species. The sublethal TRV reflects the assessment endpoint chosen as the basis for establishing risk.

### *Vegetation*

Toxicity to terrestrial plants from soil contaminants detected within the subzones is qualitatively evaluated. Risk potentials are discussed relative to literature studies and general information on phytotoxic mechanisms by selected ECPCs.

### *Aquatic Wildlife*

Potential adverse ecological effects to aquatic species from identified ECPCs are predicted based on the most conservative benchmark available (i.e., chronic water quality criteria, sediment screening values, or effects information from literature). Effects are predicted using a preliminary screening approach. Maximum water and sediment concentrations for ECPCs are divided by the available benchmark to produce an HQ. Calculated HQs for ECPCs from each media will be summed to determine an HI. HQs with a result higher than one are considered to demonstrate a potential risk. Values higher than 10 are considered to be of moderately high potential risk and above 100, extreme risk.

## **8.8 Risk Characterization**

### **8.8.1 Infaunal Invertebrates**

Most toxicological information reviewed for the infaunal invertebrates assessment (Section 8.7) dealt with earthworms and other infaunal species. It is important to note that soil in Zone C is predominantly sand and may not support these specific organisms. Although infaunal species in the sandy environment may not be the same as those dealt with in the literature, the ecological niche they occupy should be similar and, therefore, comparison to toxicological concentrations should apply.

Although some of the semivolatiles in soil are considered carcinogenic to mammals, very few field studies exist on their toxicity to terrestrial infauna. Generally, PAHs break down in natural systems via photodegradation and microbial transformation. Neuhauser et al. (1986) found that specific phenol compounds (4-nitrophenol, 2,4,6-trichlorophenol, phenol) were somewhat toxic to earthworms, with PAHs being relatively less toxic than other semivolatile compounds studied. Artificial soil tests produced lethal concentration ( $LC_{50}$ ) values for fluorene and phenol near 200 mg/kg and 400 mg/kg, respectively (refer to Table 8.6). Callahan et al. (1994) found similar results in their study on toxicity of 62 chemicals to several earthworm species. Fluorene is considered to be acutely toxic at certain concentrations but it is not considered a carcinogen. It is important to note that field variability and soil chemical matrices can greatly influence toxicological effects of PAH compounds.

Most toxicological studies on terrestrial infaunal organisms have been directed at measuring pesticide effects. Earthworm toxicology and response information is the most prevalent. In a study by Beyer and Gish (1980), persistence of DDT, dieldrin, and heptachlor was observed in earthworms from field study plots. Investigators agree that earthworms can accumulate pesticides to concentrations found in residence soil. Callahan et al. (1991) showed very good soil-to-tissue correlation ( $R = 0.725$ ), with accumulation of DDT in single earthworms up to 22 mg/kg. Beyer and Gish (1980) found that earthworms accumulated DDT to 32 mg/kg. Barker (1958) associated poisoning (lethality) of robins with 60 mg/kg DDT in earthworms, and Collett and Harrison (1968) found that blackbirds and thrushes were impacted at residues near 20 mg/kg. At concentrations observed in their study, Callahan et al. (1991) suggested that a feeding rate by robins of 10 to 12 earthworms in as many minutes (as observed by McDonald, 1983) could provide a sufficient concentration of contamination for impacts to robins. Callahan et al. (1991) also found that Chlordane, as other pesticides, was taken up rapidly by earthworms. In Callahan et al. (1991) total DDT concentrations greater than 1,000 mg/kg in soil, along with documented long half-life information (5.7 years DDT), indicated a long-term significant risk to receptors.



Risk factors associated with PCBs are similar to those for pesticides. After acute mortality, food chain biomagnification and transfer are the most important issues considered when assessing long-term risk. Paine et al. (1993) suggested a benchmark value between 100 to 300 mg/kg PCB for mortality in terrestrial insects. Also, Rhett et al. (1988) observed LC<sub>50</sub> values for earthworms treated with PCBs at 240 mg/kg. McKee (1992) reported that soil invertebrate community structure was not reduced by exposure to PCB-contaminated soil (maximum concentrations to 120,000 mg/kg wet weight) based on family level classification of invertebrates.

Reinecke and Nash (1984) studied the toxic effects of dioxin (2,3,7,8-TCDD) in soil to earthworms. For two species, *Allolobophora caliginosa* and *Lumbricus rubellus*, concentrations of 5 mg/kg or less had no acute effect, but concentrations of 10 mg/kg and above were lethal.

Most studies on metals toxicity to terrestrial receptors have been directed at infaunal ecosystems or avian biology. Information on relative metal toxicities to earthworms was provided by Roberts and Dorough (1984) where, along with 90 other chemicals, three metal salts (cadmium chloride, copper sulfate, and lead nitrate) were tested. The results showed that these heavy metal salts fell into the "very toxic" category, with LC<sub>50</sub> values in the 10 to 100 micrograms per square centimeter ( $\mu\text{g}/\text{cm}^2$ ) range. Although these concentrations (more specifically, application doses) may be relative to earthworms, it is improper to apply them to upper-level trophic species. Studies indicate that some degradation products become increasingly more toxic to earthworms and less toxic to upper-level vertebrates. Other studies on toxicities of metal salts to earthworms have been conducted by Neuhauser et al. (1986) and Malecki et al. (1982). In the former study, metal nitrate compounds were relatively toxic to earthworms in this order: copper > zinc > nickel = cadmium > lead. Mean LC<sub>50</sub> values for these metals were 643, 662, 757, 1,843 and 6,000 mg/kg, respectively. In the latter study, six chemical forms of each metal were chosen to cover a broad range of solubility and to represent the forms likely to be found in the soil. Overall, cadmium was most toxic, followed by nickel, copper, zinc, and lead. It appears obvious from the

1 results of these two studies that the form of the metal in soil in a major consideration in judging  
2 effects of their concentrations on soil biota.

3 Ma (1984) investigated sublethal effects of copper in soil to growth, cocoon production, and litter  
4 breakdown activity for *Lumbricus rubellus*. Cocoon and litter breakdown activity were  
5 significantly reduced at 131 mg/kg copper and mortality was first observed at concentrations near  
6 300 mg/kg.

7 Parmelee et al. (1993) found that total nematode/microarthropod (mostly mites) numbers declined  
8 in soil having copper concentrations above 200 mg/kg; omnivore-predator nematodes and specific  
9 microarthropod groups were significantly reduced at 100 mg/kg copper.

#### 10 Subzone-Specific Risk Characterization

11 The risk characterization for terrestrial infaunal invertebrates was determined through the  
12 comparison of the detected concentrations (maximum and mean) to the effects levels presented in  
13 Table 8.6.

#### 14 Subzone C-1

15 Within Subzone C-1 a moderate potential for risk to infaunal communities from the maximum  
16 copper concentration observed (122 mg/kg) is predicted. This concentration is similar to the 100 to  
17 150 mg/kg effect-level determined by Ma (1984), which decreased earthworm cocoon production,  
18 and just below the concentration of 150 mg/kg, which reduced earthworm populations (Nielson,  
19 1951). The mean copper concentration across the subzone, however, was only 56.8 mg/kg, well  
20 below the reported effect levels. Other maximum inorganic concentrations were also below effects  
21 levels reported in the literature. No organic data were available for soil within C-1.

## Subzone C-2

Based on a comparison of surface soil concentrations presented in Tables 8.4a and 8.4b to the effect levels presented in Table 8.7, no risks to infaunal organisms from inorganic or organic concentrations at Subzone C-2 are predicted.

### 8.8.2 Terrestrial Wildlife

Risks for the representative wildlife species associated with ingestion of surface soil and food are quantitatively evaluated using HQs, which are calculated for each ECPC by dividing the PDE concentration by the TRV. HIs are determined for each representative wildlife species by summing the HQs for all ECPCs. When the estimated PDE is less than the TRV ( $HQ < 1$ ), the contaminant exposure is assumed to fall below the range considered to be associated with adverse effects for growth, reproduction, and survival and no risks to the wildlife populations are assumed. When the HQ or HI is greater than one, the ecological significance is discussed and risk is assumed. When HIs are greater than one, the HQs constituting the HI were evaluated.

For representative terrestrial wildlife species, PDEs were calculated using available bioaccumulation data (Table 8.7) for ECPCs presented in Tables 8.3 and 8.4. Exposure parameters and assumptions for representative species at Subzones C-1 and C-2 (Tables 8.8 and 8.9, respectively) were used to calculate food contaminant concentrations. Using the model for prediction of contaminant exposure presented in Table 8.5, PDE values were obtained. HQs for both lethal and sublethal effects for ECPCs at Subzones C-1 and C-2 were determined and are presented in Tables 8.10 and 8.11, respectively, with HI values for each representative species determined. If the HI from maximum concentrations was greater than one, then the mean concentration of the parameters which comprise the HI are presented to characterize subzone-wide risk from that parameter.

**Table 8.7**  
**Bioaccumulation Data<sup>1</sup>**  
**Baseline Risk Assessment**

Analyte	Log K <sub>ow</sub>	Plant	Bioaccumulation or Biotransfer Factor (unitless)		
			Terrestrial Invertebrate	Mammal	Bird
Semivolatiles					
Anthracene	4.4 [c]	NA	0.005 [d]	6.30E-04 [a]	1 [ab]
Benzo(a)anthracene	5.74 [c]	0.019 [e]	0.0125 [d]	1.38E-02 [a]	1 [ab]
Benzo(a)pyrene	6.07 [c]	0.012 [e]	0.0342 [d]	2.95E-02 [a]	1 [ab]
Benzo(b)fluoranthene	6.32 [c]	0.008 [e]	0.032 [d]	5.25E-02 [a]	1 [ab]
Benzo(g,h,i)perylene	7 [c]	0.003 [e]	0.024 [d]	2.50E-01 [a]	1 [ab]
Benzo(k)fluoranthene	6.45 [c]	0.007 [e]	0.025 [d]	7.08E-02 [a]	1 [ab]
Bis(2-ethylhexyl)phthalate (BEHP)	5.3 [f]	0.033 [e]	0.022 [aj]	5.00E-03 [a]	1 [ab]
Butylbenzylphthalate	4.78 [g]	0.049 [e]	0.022 [aj]	1.50E-03 [a]	1 [ab]
Chrysene	5.71 [c]	0.019 [e]	0.031 [d]	1.29E-02 [a]	1 [ab]
Dibenzo(a,h)anthracene	6.42 [c]	0.008 [e]	0.022 [aj]	6.61E-02 [a]	1 [ab]
Di-n-butylphthalate	4.8 [h]	NA	0.022 [aj]	1.60E-03 [a]	1 [ab]
Fluoranthene	5.25 [c]	0.036 [e]	0.007 [d]	4.50E-03 [a]	1 [ab]
Indeno(1,2,3-cd)pyrene	7.7 [c]	0.0014 [e]	0.042 [d]	1.26E+00 [a]	1 [ab]
Phenanthrene	4.43 [c]	NA	0.012 [d]	6.70E-04 [a]	1 [ab]
Pyrene	5.09 [c]	0.044 [e]	0.018 [d]	3.10E-03 [a]	1 [ab]

**Table 8.7**  
**Bioaccumulation Data<sup>1</sup>**  
**Baseline Risk Assessment**

Analyte	Log K <sub>ow</sub>	Plant	Bioaccumulation or Biotransfer Factor (unitless)		
			Terrestrial Invertebrate	Mammal	Bird
Pesticides/PCBs/Dioxins					
Aroclor-1248	6 [c]	0.013 [e]	1.2 [i]	1.00E+00 [ak]	1 [ab]
Aroclor-1254	6.02 [c]	0.013 [e]	1.2 [i]	1.00E+00 [ak]	1 [ab]
Aroclor-1260	6 [c]	0.013 [e]	1.2 [i]	1.00E+00 [ak]	1 [ab]
alpha-Chlordane	2.78 [f]	0.027 [ac]	0.8 [j]	7.10E-01 [ak]	0.71 [ai]
gamma-Chlordane	3.32 [f]	0.027 [ac]	0.8 [j]	7.10E-01 [ak]	0.71 [ai]
4,4'-DDE	5.69 [f]	0.02 [e]	0.98 [v]	2.91E+00 [ak]	2.91 [i]
4,4'-DDT	4.48 [f]	0.027 [ac]	0.98 [v]	2.91E+00 [ak]	2.91 [i]
Dieldrin	4.95 [f]	0.049 [e]	1.2 [m]	7.10E-01 [ak]	0.71 [n]
2,3,7,8 TCDD	6.80 [am]	0.005 [e]	5.0 [b]	8.40E-01 [an]	1 [ab]
Inorganics					
Arsenic	NA	0.3 [p]	0.77 [ae]	3.60E-01 [ag]	0.45 [ah]
Barium	NA	0.56 [ag]	0.77 [ae]	3.40E-01 [af]	0.45 [ah]
Cadmium	NA	33 [q]	1.4 [k]	2.06E+00 [r]	0.38 [s]
Copper	NA	0.78 [t]	0.16 [i]	6.00E-01 [q]	0.45 [ah]
Lead	NA	0 [q]	0.22 [u]	5.40E-01 [w]	0.45 [ah]
Manganese	NA	0.56 [ag]	0.77 [ae]	3.40E-01 [ag]	0.45 [ah]
Mercury	NA	0.56 [ag]	0.34 [x]	1.00E-02 [aa]	2.33 [aa]



**Table 8.7**  
**Bioaccumulation Data<sup>1</sup>**  
**Baseline Risk Assessment**

Analyte	Log K <sub>ow</sub>	Plant	Bioaccumulation or Biotransfer Factor (unitless)		
			Terrestrial Invertebrate	Mammal	Bird
Inorganics (continued)					
Selenium	NA	0.009 [y]	0.77 [ae]	3.40E-01 [af]	0.51 [z]
Zinc	NA	0.61 [t]	1.77 [i]	2.06E+00 [w]	0.45 [ah]

**Notes:**

- [a] = Calculated using the following equation (Travis and Arms, 1988), unless otherwise noted:  $\log \text{BAF} = \log K_{ow} - 7.6$ ; result multiplied by average of ingestion rates for non-lactating and lactating test animals. There is an uncertainty involved in using this equation for PAHs, because this study did not use any PAHs in the regression analysis.
- [b] = Reinecke and Nash (1984).
- [c] = Geometric mean of values from USEPA (1986).
- [d] = Marquerie et al. (1987) as cited in Beyer (1990). Mean of values. Converted to wet weight assuming 90% body weight as water.
- [e] = Calculated using the following equation in Travis and Arms (1988) for analytes with  $\log K_{ow} > 5$ :  $\log (\text{Plant Uptake Factor}) = 1.588 - 0.578 \log K_{ow}$ .
- [f] = From USEPA (1986).
- [g] = Value from Verschueren (1983).
- [h] = Value from Howard (1990).
- [i] = BCF for earthworms from Diercxsens, et al. (1985).
- [j] = Value from Gish (1970).
- [k] = Mean of values reported for soil invertebrates in Macfadyen (1980) converted from dry weight to wet weight.
- [l] = Whole body pheasant BAF for 4,4'-DDT presented in USEPA (1985), derived from Kenaga (1973).
- [m] = Average of values reported for soil invertebrates in Edwards and Thompson (1973).
- [n] = Jeffries and Davis (1968).
- [o] = Value reported for endrin from Gish (1970).
- [p] = Average of BAF values reported from Wang et al. (1984), Sheppard et al. (1985) and Merry et al. (1986).
- [q] = Levine et al. (1989).
- [r] = Mean of values reported for *Sorex araneus* in Macfadyen (1980).
- [s] = Based on accumulation of cadmium in kidneys of European quail in Pimentel et al. (1984).

**Notes: (continued):**

- [t] = Median of values reported from Levine et al. (1989).
- [u] = Geometric mean of BAF values (fresh st. worm/dry st. soil) for worms and woodlice (USEPA, 1985). Fresh weight tissue concentrations calculated assuming 90% body water content.
- [v] = Beyer and Gish (1980) reported dry weight to wet weight ratio.
- [w] = Mean of values for *Microtus agrestis* and *Apodemus sylvaticus* in Macfadyen (1980).
- [x] = Value from USEPA (1985) sludge document.
- [y] = Based on reported ratio of selenium in plant tissue and iron fly ash amended soil (Stoewsand et al., 1978).
- [z] = Based on average of reported ratio of selenium in diet to liver, kidney, and breast tissue of chickens (Ort and Latshaw, 1977).
- [aa] = USEPA, 1985.
- [ab] = Assumption.
- [ac] = Assumed value based on average of BAFs calculated for other pesticides and PCBs.
- [ad] = Assumed value base on average of BAFs for Aroclor 1260, alpha-chlordane, 4,4'-DDE, Dieldrin and endrin ketone.
- [ae] = Assumed value based on average of BAFs reported for other metals.
- [af] = Assumed value based on average of reported BAFs for Cd, Cu, Pb and Hg.
- [ag] = Assumed value based on average of reported BAFs for As, Cu, Hg and Zn.
- [ah] = Assumed value based on average of reported BAF values for Cd and Se.
- [ai] = Assumed value based on reported BAF for dieldrin.
- [aj] = Assumed value based on average of BAFs for semivolatiles.
- [ak] = Value for mammal unavailable. Bioaccumulation assumed to be the same as values reported for birds.
- [am] = Polder et al. (1995).
- [an] = Rose et al. (1976).
- [ao] = Travis and Arms (1988).
- [ap] = van Gestel and Ma (1988).
- NA = Not available.
- <sup>1</sup> = Table adapted from BRA, NAS Cecil Field, Jacksonville, Florida.

**Table 8.8**  
**Exposure Parameters and Assumptions for Representative Wildlife Species at Subzone C-1**

Representative Wildlife Species	Trophic Status	Prey in Diet (%)					Incidental Soil Ingestion (%)	Home Range (acres)	ED	Site Foraging Factor (SFF)	Ingestion Rate (kg/day)	Body Weight (kg)
		Inverts	Plants	Small Mammals	Herpeto- fauna	Small Birds						
American Robin <sup>a</sup>	Small Carnivorous Bird	83	7	0	0	0	10	1.04	1	9.13e-01	0.10	0.077
Eastern Cottontail <sup>b</sup>	Small Herbivorous Mammal	0	97	0	0	0	3	9.3	1	1.02e-01	0.08	1.2
Short-tailed Shrew <sup>c</sup>	Small Carnivorous Mammal	78	12	0	0	0	10	0.96	1	1.00e+00	0.0025	0.018
SITE AREA: 0.95 acres												

**Notes:**

- a = — Diet assumptions based on data from Hamilton, 1943 and Wheelwright, 1986.  
— Food ingestion rate (FI) from formula:  $FI(kg/day) = 0.0582 W^{0.651} (kg)$  (Nagy, 1987).  
— Body weight from Clench & Leberman, 1978.  
— Home range reflects interpolated values from Howell, 1992; and Weatherhood & McRae, 1990.
- b = — Diet assumptions based on data from Dusi, 1952; and Spencer & Chapman, 1986.  
Food ingestion rate (FI) from formula:  $FI(kg/day) = 0.0687 \times W^{0.822} (kg)$  (Nagy, 1987).  
Body weight reflects interpolated values from Chapman & Morgan 1973; Pelton & Jenkins, 1970.  
Home range reflects interpolated values from Althoff & Storm, 1989; and Dixon et al., 1981.
- c = — Diet assumption based on data from Whitaker & Ferraro, 1963.  
Food ingestion rate (FI) from formula:  $FI(kg/day) = 0.0687 \times w^{0.822} (kg)$  (Nagy, 1987).  
Body weight from Lomolino, 1984.  
Home range value from Buckner, 1966.
- ED = Exposure Duration (percentage of year receptor is expected to be found at study area expressed as a factor, i.e., 100% = 1.0)
- SFF = Site area (acres) times exposure duration (ED) divided by Home Range (HR); cannot exceed 1.0.

**Table 8.9**  
**Exposure Parameters and Assumptions for Representative Wildlife Species at Subzone C-2**

Representative Wildlife Species	Trophic Status	Prey in Diet (%)					Incidental Soil Ingestion (%)	Home Range (acres)	ED	Site Foraging Factor (SFF)	Ingestion Rate (kg/day)	Body Weight (kg)
		Inverts	Plants	Small Mammals	Herpeto- fauna	Small Birds						
American Robin <sup>a</sup>	Small Carnivorous Bird	83	7	0	0	0	10	1.04	1	1.00e+00	0.10	0.077
Eastern Cottontail <sup>b</sup>	Small Herbivorous Mammal	0	97	0	0	0	3	9.3	1	2.31e-01	0.08	1.2
Short-tailed Shrew <sup>c</sup>	Small Carnivorous Mammal	78	12	0	0	0	10	0.96	1	1.00e+00	0.0025	0.018
SITE AREA: 2.15 acres												

**Notes:**

- a = Diet assumptions based on data from Hamilton, 1943 and Wheelwright, 1986.  
Food ingestion rate (FI) from formula:  $FI(kg/day) = 0.0582 W^{0.651} (kg)$  (Nagy, 1987).  
Body weight from Clench & Leberman, 1978.  
Home range reflects interpolated values from Howell, 1992; and Weatherhood & McRae, 1990.
- b = Diet assumptions based on data from Dusi, 1952; and Spencer & Chapman, 1986.  
Food ingestion rate (FI) from formula:  $FI(kg/day) = 0.0687 \times W^{0.822} (kg)$  (Nagy, 1987).  
Body weight reflects interpolated values from Chapman & Morgan 1973; Pelton & Jenkins, 1970.  
Home range reflects interpolated values from Althoff & Storm, 1989; and Dixon et al., 1981.
- c = Diet assumption based on data from Whitaker & Ferraro, 1963.  
Food ingestion rate (FI) from formula:  $FI(kg/day) = 0.0687 \times W^{0.822} (kg)$  (Nagy, 1987).  
Body weight from Lomolino, 1984.  
Home range value from Buckner, 1966.
- ED = Exposure Duration (percentage of year receptor is expected to be found at study area expressed as a factor, i.e., 100% = 1.0)
- SFF = Site area (acres) times exposure duration (ED) divided by Home Range (HR); cannot exceed 1.0.

**Table 8.10a**  
**Hazard Quotients for Potential Lethal Effects for Wildlife Species Associated with**  
**Maximum Exposure Concentrations of ECPCs in Surface Soil at Subzone C-1**

Analyte	Maximum Concentration (mg/kg)	American Robin			Eastern Cottontail Rabbit			Short-tailed Shrew		
		PDE	TRV	HQ	PDE	TRV	HQ	PDE	TRV	HQ
Aluminum	36,600	NC	NA	NC	NC	NA	NC	NC	NA	NC
Arsenic	103	9.28e+00	NA	NC	2.25e-01	1.53e+02	1.47e-03	1.57e+01	2.90e+01	5.41e-01
Beryllium	2.0	NC	NA	NC	NC	NA	NC	4.54e-02	NA	NC
Cadmium	3.6	1.52e+00	NA	NC	7.84e-01	3.00e+01	2.61e-02	1.46e+01	1.78e+02	8.20e-02
Chromium	54.3	NC	NA	NC	NC	NA	NC	NC	NA	NC
Cobalt	13.6	NC	NA	NC	NC	NA	NC	NC	NA	NC
Copper	122	4.16e+00	NA	NC	6.53e-01	2.40e+02	2.72e-03	1.78e+01	NA	NC
Iron	99,500	NC	NA	NC	NC	NA	NC	NC	NA	NC
Mercury	0.53	2.65e-02	2.50e+00	1.06e-02	2.07e-03	3.60e+00	5.75e-04	5.21e-02	4.40e+00	1.18e-02
Nickel	43.4	NC	NA	NC	NC	NA	NC	NC	NA	NC
Selenium	8.8	7.72e-01	NA	NC	2.32e-03	1.30e+03	1.78e-06	1.10e+00	1.30e+02	8.46e-03
Thallium	2.4	NC	NA	NC	NC	NA	NC	NC	NA	NC
Vanadium	68.2	NC	1.90e+01	NC	NC	NA	NC	NC	NA	NA
Lethal HI =		1.06e-02			3.09e-02			6.44e-01		

**Notes:**

- NA = Data are not available.
- NC = Not able to calculate value.
- PDE = Potential Dietary Exposure (mg/kg/BW) calculated based on equation in Table 8.5.
- TRV = Toxicity Reference Value (mg/kg/BW/day) - 1/5 of the lowest reported LD<sub>50</sub> value from Appendix G for closest related species.
- HQ = Hazard Quotient - PDE divided by the TRV.
- HI = Hazard Index (HQ<sub>1</sub> + HQ<sub>2</sub> + ...HQ<sub>n</sub>).



Table 8.10b  
Hazard Quotients for Potential **Lethal** Effects for Wildlife Species Associated with  
Mean Exposure Concentrations of ECPCs in Surface Soil at Subzone C-1

Analyte	Mean Concentration (mg/kg)	American Robin			Eastern Cottontail Rabbit			Short-tailed Shrew		
		PDE	TRV	HQ	PDE	TRV	HQ	PDE	TRV	HQ
Aluminum	18,967.67	NC	NA	NC	NC	NA	NC	NC	NA	NC
Arsenic	44.13	3.98e+00	NA	NC	9.63e-02	1.53e+02	6.29e-04	6.72e+00	2.90e+01	2.32e-01
Beryllium	1.35	NC	NA	NC	NC	NA	NC	NC	2.00e+00	NC
Cadmium	2.06	8.72e-01	NA	NC	4.49e-01	3.00e+01	1.50e-02	6.36e+00	4.48e+02	1.42e-02
Chromium	36.17	NC	NA	NC	NC	NA	NC	NC	NA	NC
Cobalt	9.27	NC	NA	NC	NC	NA	NC	NC	NA	NC
Copper	56.8	1.94e+00	NA	NC	3.04e-01	2.40e+02	1.27e-03	8.31e+00	NA	NC
Iron	44,973.33	NC	NA	NC	NC	NA	NC	NC	NA	NC
Mercury	0.34	1.70e-02	2.50e+00	6.80e-03	1.33e-03	3.60e+00	3.69e-04	3.34e-02	4.40e+00	7.59e-03
Nickel	31.43	NC	NA	NC	NC	NA	NC	NC	NA	NC
Selenium	4.76	4.18e-01	NA	NC	1.25e-03	1.30e+02	9.62e-06	6.02e-01	1.30e+02	4.63e-03
Thallium	2.4	NC	NA	NC	NC	NA	NC	NC	NA	NC
Vanadium	39.10	NC	1.90e+01	NC	NC	NA	NC	NC	NA	NC
Lethal HI =		6.80e-03			1.72e-02			2.58e-01		

**Notes:**

NA = Data are not available.  
NC = Not able to calculate value.  
PDE = Potential Dietary Exposure (mg/kg/BW) calculated based on equation in Table 8.5.  
TRV = Toxicity Reference Value (mg/kg/BW/day) - 1/5 of the lowest reported LD<sub>50</sub> value from Appendix G for closest related species.  
HQ = Hazard Quotient - PDE divided by the TRV.  
HI = Hazard Index (HQ<sub>1</sub> + HQ<sub>2</sub> + ...HQ<sub>n</sub>).

**Table 8.10c**  
**Hazard Quotients for Potential Sublethal Effects for Wildlife Species Associated with**  
**Maximum Exposure Concentrations of ECPCs in Soil at Subzone C-1**

Analyte	Maximum Concentration (mg/kg)	American Robin			Eastern Cottontail Rabbit			Short-tailed Shrew		
		PDE	TRV	HQ	PDE	TRV	HQ	PDE	TRV	HQ
Aluminum	36,600	NC	NA	NC	NC	NA	NC	NC	NA	NC
Arsenic	103	9.28e+00	NA	NC	2.25e-01	5.80e-01	3.88e-01	1.57e+01	5.80e-01	2.71e+01
Beryllium	2.0	NC	NA	NC	NC	NA	NC	NC	NA	NC
Cadmium	3.6	1.52e+00	1.00e+01	1.52e-01	7.84e-01	2.20e+01	3.56e-02	1.11e+01	4.48e+02	2.48e-02
Chromium	54.3	NC	NA	NC	NC	NA	NC	NC	NA	NC
Cobalt	13.6	NC	NA	NC	NC	NA	NC	NC	NA	NC
Copper	122	4.16e+00	1.10e+01	3.78e-01	6.53e-01	1.50e+02	4.35e-03	1.78e+01	1.50e+02	1.19e-01
Iron	99,500	NC	NA	NC	NC	NA	NC	NC	NA	NC
Mercury	0.53	2.65e-02	6.40e-02	4.14e-01	2.07e-03	5.00e-01	4.13e-01	5.21e-02	5.00e-01	1.04e-01
Nickel	43.4	NC	NA	NC	NC	NA	NC	NC	NA	NC
Selenium	8.8	7.72e-01	1.80e+00	4.29e-01	2.32e-03	1.50e+02	1.78e-05	1.10e+00	1.50e+02	8.46e-03
Thallium	2.4	NC	NA	NC	NC	NA	NC	NC	NA	NC
Vanadium	68.2	NC	1.90e+01	NC	NC	NA	NC	NC	NA	NC
Sublethal HI =		1.37e+00			8.41e-01			2.73e+01		

**Notes:**

NA = Data are not available.  
 NC = Not able to calculate value.  
 PDE = Potential Dietary Exposure (mg/kg/BW) calculated based on equation in Table 8.5.  
 TRV = Toxicity Reference Value (mg/kg/BW/day) - the lowest LOAEL from Appendix G.  
 HQ = Hazard Quotient - PDE divided by the TRV.  
 HI = Hazard Index (HQ<sub>1</sub> + HQ<sub>2</sub> + ...HQ<sub>n</sub>).

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**Table 8.11a**  
**Hazard Quotients for Potential Lethal Effects for Wildlife Species Associated with**  
**Maximum Exposure Concentrations of ECPCs in Soil at Subzone C-2**

Analyte	Max Conc (mg/kg)	American Robin			Eastern Cottontail Rabbit			Short-tailed Shrew		
		PDE	TRV	HQ	PDE	TRV	HQ	PDE	TRV	HQ
Benzo(a)anthracene	0.140	2.03e-03	NA	NC	1.04e-04	NA	NC	2.52e-03	NA	NC
Benzo(b)fluoranthene	0.270	4.46e-03	NA	NC	1.57e-04	NA	NC	6.05e-03	NA	NC
Benzo(k)fluoranthene	0.300	4.27e-03	NA	NC	1.70e-04	NA	NC	6.92e-03	NA	NC
Benzo(a)pyrene	0.120	2.01e-03	NA	NC	7.70e-05	1.00e+01	7.70e-06	2.53e-03	1.00e+01	2.53e-04
Chrysene	0.170	2.81e-03	NA	NC	1.27e-04	NA	NC	3.38e-03	NA	NC
Fluoranthene	0.240	3.38e-03	NA	NC	2.40e-04	NA	NC	4.33e-03	NA	NC
Phenanthrene	0.120	NC	NA	NC	NA	NA	NC	NA	NA	NC
Pyrene	0.210	3.22e-03	NA	NC	2.35e-04	5.40e+02	4.85e-07	4.15e-03	1.60e+02	2.59e-05
Aldrin	0.0011	NC	NA	NC	NC	NA	NC	NC	NA	NC
beta-BHC	0.0084	NC	NA	NC	NC	NA	NC	NC	NA	NC
Chlordane	0.0042	4.18e-05	4.80e+00	8.70e-05	3.63e-06	2.00e+01	1.82e-07	6.80e-04	5.70e+01	1.20e-05
4,4'-DDD	0.037	NC	NA	NC	NC	NA	NC	NC	NA	NC
4,4'-DDE	0.190	2.26e-02	NA	NC	1.64e-04	1.60e+02	3.90e-04	6.93e-02	1.04e+02	4.95e-04
4,4'-DDT	0.067	7.96e-03	8.00e+02	9.95e-06	5.80e-05	5.00e+01	1.10e-05	2.44e-02	2.70e+01	9.05e-04
Aroclor 1254	0.060	8.55e-03	3.00e+02	2.85e-05	3.94e-05	2.00e+00	1.97e-05	1.47e-02	2.00e+01	6.85e-04
Dieldrin	0.002	2.86e-04	9.60e+00	2.98e-05	2.39e-06	9.00e+00	1.10e-06	4.14e-04	7.60e+00	5.45e-05
Disulfoton	0.0052	NC	NA	NC	NC	NA	NC	NC	NA	NC
Endosulfan	0.0024	2.00e-04	6.20e+00	3.20e-05	4.87e-06	4.80e+00	1.00e-06	1.57e-04	4.80e+00	3.30e-05
Endrin aldehyde	0.0013	NC	NA	NC	NC	NA	NC	NC	NA	NC
Methoxychlor	0.0043	NC	NA	NC	NC	NA	NC	NC	NA	NC

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**Table 8.11a**  
**Hazard Quotients for Potential Lethal Effects for Wildlife Species Associated with**  
**Maximum Exposure Concentrations of ECPCs in Soil at Subzone C-2**

Analyte	Max Conc (mg/kg)	American Robin			Eastern Cottontail Rabbit			Short-tailed Shrew		
		PDE	TRV	HQ	PDE	TRV	HQ	PDE	TRV	HQ
Methyl parathion	0.0047	NC	NA	NC	NC	NA	NC	NC	NA	NC
Sulfotepp	0.0045	NC	NA	NC	NC	NA	NC	NC	NA	NC
Vinyl acetate		NC	NA	NC	NC	NA	NC	NC	NA	NC
2,4,5-T	0.0085	NC	NA	NC	NC	NA	NC	NC	NA	NC
Beryllium	0.44	NC	NA	NC	NC	NA	NC	NC	NA	NC
Iron	11,800	NC	NA	NC	NC	NA	NC	NC	NA	NC
Manganese	280	2.83e+01	NA	NC	2.47e+00	8.00e+01	3.09e-02	4.82e+01	4.50e+01	1.07e+00
Lethal HI =		1.87e-04			3.13e-02			1.07e+00		

**Notes:**

Max Conc = Maximum Concentration of Analyte.

NA = Data are not available.

NC = Not able to calculate value.

PDE = Potential Dietary Exposure (mg/kg/BW) calculated based on equation in Table 8.5.

TRV = Reference Toxicity Value (mg/kg/BW/day) - 1/5 of the lowest reported LD<sub>50</sub> value from Appendix G for closest related species.

HQ = Hazard Quotient - PDE divided by the TRV.

HI = Hazard Index (HQ<sub>1</sub> + HQ<sub>2</sub> + ...HQ<sub>n</sub>).

Table 8.11b  
 Hazard Quotients for Potential Sub-Lethal Effects for Wildlife Species Associated with  
 Maximum Exposure Concentrations of ECPCs in Soil at Subzone C-2

Analyte	Max Conc (mg/kg)	American Robin			Eastern Cottontail Rabbit			Short-tailed Shrew		
		PDE	TRV	HQ	PDE	TRV	HQ	PDE	TRV	HQ
Benzo(a)anthracene	0.140	2.03e-03	NA	NC	1.04e-04	NA	NC	2.52e-03	NA	NC
Benzo(b)fluoranthene	0.270	4.46e-03	NA	NC	1.57e-04	NA	NC	6.05e-03	NA	NC
Benzo(k)fluoranthene	0.300	4.27e-03	NA	NC	1.70e-04	NA	NC	6.92e-03	NA	NC
Benzo(a)pyrene	0.120	2.01e-03	NA	NC	7.70e-05	4.00e+01	1.93e-06	2.53e-03	4.00e+01	6.33e-05
Chrysene	0.170	2.81e-03	NA	NC	1.27e-04	NA	NC	3.38e-03	NA	NC
Fluoranthene	0.240	3.38e-03	NA	NC	2.40e-04	NA	NC	4.33e-03	NA	NC
Phenanthrene	0.120	NC	NA	NC	NA	NA	NC	NA	NA	NC
Pyrene	0.210	3.22e-03	NA	NC	2.35e-04	NA	NC	4.15e-03	NA	NC
Aldrin	0.0011	NC	NA	NC	NC	NA	NC	NC	NA	NC
beta-BHC	0.0084	NC	NA	NC	NC	NA	NC	NC	NA	NC
Chlordane	0.0042	4.18e-05	NA	NC	3.63e-06	NA	NC	6.80e-04	NA	NC
4,4'-DDD	0.037	NC	NA	NC	NC	NA	NC	NC	NA	NC
4,4'-DDB	0.190	2.26e-02	5.80e-01	3.90e-02	1.64e-04	NA	NC	6.93e-02	NA	NC
4,4'-DDT	0.067	7.96e-03	1.40e-01	5.69e-02	5.80e-05	1.50e+02	3.87e-07	2.44e-02	8.10e+01	3.01e-04
Aroclor 1254	0.060	8.55e-03	9.00e-01	9.50e-03	3.94e-05	9.60e-02	4.10e-04	1.47e-02	1.53e+00	9.61e-03
Dieldrin	0.002	2.86e-04	NA	NC	2.39e-06	NA	NC	4.14e-04	3.30e-01	1.25e-03
Disulfoton	0.0052	NC	NA	NC	NC	NA	NC	NC	NA	NC
Endosulfan	0.0024	2.00e-04	NA	NC	4.87e-06	NA	NC	1.57e-04	NA	NC
Endrin aldehyde	0.0013	NC	NA	NC	NC	NA	NC	NC	NA	NC
Methoxychlor	0.0043	NC	NA	NC	NC	NA	NC	NC	NA	NC



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Table 8.11b  
Hazard Quotients for Potential Sub-Lethal Effects for Wildlife Species Associated with  
Maximum Exposure Concentrations of ECPCs in Soil at Subzone C-2

Analyte	Max Conc (mg/kg)	American Robin				Eastern Cottontail Rabbit				Short-tailed Shrew			
		PDE	TRV	HQ		PDE	TRV	HQ		PDE	TRV	HQ	
Methyl parathion	0.0047	NC	NA	NC		NC	NA	NC		NC	NA	NC	
Sulfotepp	0.0045	NC	NA	NC		NC	NA	NC		NC	NA	NC	
Vinyl acetate		NC	NA	NC		NC	NA	NC		NC	NA	NC	
2,4,5-T	0.0085	NC	NA	NC		NC	NA	NC		NC	NA	NC	
Beryllium	0.44	NC	NA	NC		NC	NA	NC		NC	NA	NC	
Iron	11,800	NC	NA	NC		NC	NA	NC		NC	NA	NC	
Manganese	280	2.83e+01	NA	NC		2.47e+00	NA	NC		4.82e+01	1.40e+02	3.45e-01	
Sublethal HI =				1.05e-01				4.13e-04				3.56e-01	

Notes:  
Max Conc = Maximum Concentration of Analyte.  
NA = Data are not available  
NC = Not able to calculate value.  
PDE = Potential Dietary Exposure (mg/kg/BW) calculated based on equation in Table 8.5.  
TRV = Toxicity Reference Value (mg/kg/BW/day) - lowest reported LOAEL from Appendix G.  
HQ = Hazard Quotient - PDE divided by the TRV.  
HI = Hazard Index (HQ<sub>1</sub> + HQ<sub>2</sub> + ...HQ<sub>n</sub>).

## **Subzone-Specific Risk Characterization**

### ***Subzone C-1***

All lethal HQ and HI values calculated for each of the representative wildlife species selected for maximum (point specific risk) soil concentrations in Subzone C-1 were less than one (Table 8.10a). No potential lethal effects exist as a result of exposure to ECPs in surface soil.

Using the maximum concentrations for HQ calculations, potential sublethal effects to small vertebrates and avian species from soil contamination at Subzone C-1 are present based on the modeled HI value (shrew HI=27.3 and robin HI=1.37). For the shrew, the maximum arsenic concentration of 103 mg/kg (HQ = 27.1) for the short-tailed shrew was almost entirely responsible for the produced HI value. Using the mean arsenic concentration (44.13 mg/kg) at Subzone C-1, the shrew's sub-lethal HQ is reduced to 11.6, still indicating a moderate sub-lethal risk.

For the robin, no individual HQs exceeded one, however the HI slightly exceeds one due to the elevated HQs of selenium, mercury, copper, and cadmium. Using the mean concentration, however, the HI drops well below one.

The risk potential for the shrew produced by the model contradicts some of the literature on arsenic transfer to small mammals. Pascoe et al. (1994) found that the bioavailable fraction of arsenic in soils to small mammals was limited. But results of the model agree with other studies that show transfer of metal to small mammals via plant uptake from soils to be feasible (Leita et al., 1991). Measurement of tissue concentrations or in-situ bioaccumulation studies would be necessary to assess the actual potential for impacts to small mammals at Subzone C-1.

### **Subzone C-2**

The lethal HQ and HI values calculated using the maximum soil concentration in Subzone C-2 indicate a slight potential for lethal effects to the short-tailed shrew (HI=1.07). Manganese (HQ=1.07 [rounded]) is almost entirely responsible for the HI. The HIs for each of the remaining representative wildlife species were less than one (Table 8.11a). Using the mean concentration for manganese, the shrew's HQ drops to 0.354, indicating that lethal effects from subzone-wide manganese concentrations in surface soil are unlikely .

No potential sub-lethal effects from exposure to ECPCs in soil at Subzone C-2 exists based on the model prediction. All sub-lethal HQ and HI values calculated for terrestrial species for potential effects from soil contamination in Subzone C-2 were less than one (Table 8.11b).

### **8.8.3 Vegetation**

Limited information exists on toxic effects of soil contamination to plants in natural environments. Most literature containing effects information deals with herbicide or fungicide application programs. Beyer et al. (1985) demonstrated that only a small portion of all metals measured in soil became incorporated in plant foliage. In their study, the origin for plant metal residues was suggested to have come primarily from aerial deposition. Table 8.12 presents phytotoxic effects levels for arsenic, lead and zinc for several species. Effects levels vary depending on specific soil physico-chemical conditions such as pH, organic content, and cation-exchange-capacity.

Arsenic availability to plants is typically highest in coarse-textured soils having little cation exchange capacity and lowest in clay having organic material, and containing iron, calcium and phosphate (NRCC, 1978). Cadmium appears to be taken up by plants in soils that have abnormally high cadmium residues. For chromium, Towill et al.'s (1978) study showed no phytotoxic effects to plants for elevated chromium levels.

Table 8.12  
Summary of Chemical Effects Studies on Vegetation

Study	Organisms	Measured Parameter	Effects Level (mg/kg)	Measured Response
USEPA (1987)	<i>Acer rubrum</i> , Red Maple	Zinc	100	Lethal to seedlings
USEPA (1987)	<i>Quercus rubra</i> , Oak	Zinc	100	Lethal to seedlings
NRCC (1978)	Canadian crops	Arsenic	25-85	Depressed crop yield
	<i>Oryza sativum</i> , Rice	Arsenic (disodium methylarsenate)	50	75 % decrease yield
Sadiq (1985)	Corn plant	Lead	800	No elevated concentration in plants
Krishnayya and Bodi (1986)	<i>Cassia spp.</i> , Weeds	Lead	300	90 % reduced pollen germination
Miller et al. (1985)	Radish (seed germination)	Copper	47	EC 50
		Zinc	53	EC 50
	Cucumber (see germination)	Copper	55	EC 50
		Zinc	61	EC 50

Like other metals, the bioavailability of lead in soil to plants is enhanced by reduced soil pH, reduced organic matter, and reduced iron oxides and phosphorous content (NRCC, 1973). Studies have shown that there is no convincing evidence that terrestrial vegetation is important in food chain biomagnification of lead (USEPA, 1980). Chang et al. (1983) observed that zinc uptake was lower in coarse loamy soils than in fine loamy soils. The phytotoxic nature of copper to crop production has been studied relative to application rates (Hirst, et al. 1961). Little information exists on mercury effects to higher plants (Eisler, 1987b).

Studies by USEPA (1980), Lee and Grant (1981), Wang and Meresz (1982) and Edwards (1983) generally conclude six points for PAH's effects to plants. First, plants can absorb PAHs from soil through roots to other parts. Second, lower molecular weight compounds are absorbed more readily than higher molecular weight compounds. Third, aboveground parts have higher residue levels, which are most likely attributable to airborne deposition. Fourth, PAH-induced phytotoxic effects are rare. Fifth, higher plants can catabolize benzo(a)pyrene and possibly other PAH compounds, and finally, plant up-take of PAHs is most likely not a significant pathway to terrestrial vertebrate species.

For PCBs, Klekowski (1982) suggested that there was no evidence of genetic damage to terrestrial plants at a PCB-contaminated site in Massachusetts.

For dioxins, Isensee and Jones (1971) indicated that isomer were less readily taken up by terrestrial plants was less readily compared to aquatic plants, and studies by Blair (1973) and Ramel (1978) considered uptake of 2,3,7,8-TCDD from soils by vegetation to be negligible.

Eisler (1990) noted that there was little information available on phytotoxicity of chlordane and that there was little evidence to indicate accumulation by crop plants. In soils, chlordane is mostly



immobile and there is only a limited capacity for translocation into edible portions of food crops (NRCC, 1975).

### **Subzone-Specific Risk Characterization**

#### ***Subzone C-1***

Based on the maximum concentration of copper (122 mg/kg) and considering the physical nature of soil within Subzone C-1, a potential risk to woody seedlings and young herbaceous species exists. Also, the arsenic concentration (103 mg/kg) was above the effect level reported for impacts to rice crops in Canada (NRCC, 1978). The potential impact of arsenic in a natural field setting cannot be determined. Effects from organic concentrations could not be assessed.

#### ***Subzone C-2***

A potential risk to woody seedlings and young herbaceous species exists from metal contamination observed in Subzone C-2 soil. Copper (117 mg/kg), lead (339 mg/kg), and zinc (410 mg/kg) concentrations were above effects levels reported in literature. Effects from organic concentrations could not be assessed.

### **8.8.4 Aquatic Wildlife**

Risk to aquatic receptors present in Noisette Creek will be fully addressed during the Zone J RFI.

#### ***Subzone C-1***

Contamination in surface water and sediments were measured to assess the potential for risk to aquatic receptor species. The maximum concentration of 10 of the 14 inorganic ECPCs detected in surface water exceed their respective surface water criteria effects level (see Table 8.3c). Aluminum, iron, and copper are the most critical ECPCs (HQs = 189, 85.9 and 14.1, respectively) with beryllium, lead, zinc, selenium, and cadmium each having HQs between

1 and 10. Overall, based on the concentrations observed, a moderate to high risk to aquatic receptors exists from inorganic constituents present in surface water.

A potential risk to aquatic receptors from maximum sediment concentrations at Subzone C-1 exists based on exceedances of USEPA Region V Sediment Screening Values (see Table 8.3b). Using the maximum concentrations, HQ values greater than one were determined for the following ECPCs: arsenic (9.3), copper (4.0), lead (1.4), and mercury (12.3). Only the maximum HQ for mercury was greater than 10. Using the mean sediment concentrations, the HQ for mercury drops to 4.54, with arsenic having the highest HQ (5.56) followed by copper and lead (HQs=1.81 and 1.06, respectively). Because SSVs are derived from statistical interpretation of effects databases obtained from literature, actual risks to receptors within the surface water at C-1 may be lower than that implied by use of the SSV in the screening assessment.

Although effects levels were exceeded in both media (water and sediment), it is predicted that specific impacts to receptors would be difficult to determine without actual biological testing. However, since concentrations only minimally exceed screening values a risk management decision needs to be made whether or not biological sampling is really necessary.

## **8.9 Uncertainty**

General uncertainties are associated with ERA for Zone C.

- Degradation of chemicals has not been considered in the ECPC selection process.
- Specific effects to biota within the area are unknown.
- Acute and chronic effects data on some ECPCs were unavailable.

- Synergistic or antagonistic effects cannot be quantified. 1
- For some ECPCs, only assumptions relative to similar compounds or classes of elements  
can be made. 2 3
- Use of related species for risk determination may over or underestimate risk to selected  
representative wildlife species. 4 5
- Dermal or inhalation exposure pathways were not evaluated. 6
- Maximum exposure scenarios and concentrations may tend to overestimate risk potentials. 7
- On occasion, BAFs were assumed due to lack of information. 8
- Actual occurrence of selected wildlife species within the contaminated area is uncertain. 9
- Food ingestion rates in food chain analyses may be a source of uncertainty to exposure. 10
- Sediment screening values are obtained from laboratory studies and may not reflect field-  
based exposure scenarios. 11 12

#### **8.10 Risk Summary**

Risk for ecological receptors was evaluated for ECPCs in surface soil, surface water, and sediment at Subzone C-1 and for soil only at Subzone C-2. This is primarily because of the change in scope to the Final Zone J RFI work plan. By the time these changes were implemented, field work for Zone C had already been completed as originally proposed and report preparation was underway, thus creating data gaps for sediments and surface water in Subzone C-2. Risk associated with

exposure to ECPCs in surface soil was evaluated for terrestrial wildlife based on a model that predicts the amount of contaminant exposure via the diet and incidental ingestion of soil. The risk evaluation is based on a comparison of predicted doses for representative wildlife species with doses representing thresholds for both lethal and sublethal effects (TRVs). Risk for soil invertebrates and plants was evaluated based on qualitative comparison to literature effects levels for taxonomic groups similar to those potentially occurring at Zone C. Risk for aquatic organisms were evaluated by calculating HQs from benchmark values that are either promulgated or proposed by federal and state regulatory agencies.

*Infaunal Invertebrates* — Based on the effect levels, the maximum concentration of copper poses a moderate risk potential to infaunal invertebrate species within Subzone C-1. The mean HQ for copper, however, was well below the effect level. All other maximum concentrations in both subzones were below their respective effect level (Table 8.6).

*Terrestrial Wildlife* — No risk potential for lethal effects to terrestrial wildlife exist based on soil ECPCs within Subzones C-1. All HQ and HI values calculated for each of the representative wildlife species within each subzones were less than one (Tables 8.10a)

Using the maximum concentrations in Subzone C-2, the model predicts a slight risk potential (HI=1.07) for lethal effects to the short-tailed shrew from exposure to manganese in surface soil (Table 8.11a).

Potential sub-lethal effects to both small vertebrates (shrew) and avian species (robin) exist at Subzone C-1. A moderate risk to the shrew from exposure to arsenic in surface soil (HI=27.3).

Based on the sub-lethal HI generated by the model for the American robin, cumulative exposure to selenium, mercury, copper and cadmium in surface soil presents a low potential for excess risk (HI=1.37), although the HQ for each analyte is below 1.

*Vegetation* — A potential risk to woody seedlings and young herbaceous species exist at Subzones C-1 and C-2. At C-1, maximum concentrations of copper and arsenic constitute the risk. At C-2 copper, lead, manganese, and zinc concentrations are above effect levels reported in literature. Organic concentrations could not be assessed.

*Aquatic Receptors* — Aquatic receptors present in Subzone C-1 do not appear to be at risk or significantly impacted.

A potential risk to aquatic receptors exists in sediments at Subzone C-1 because HQ values derived from the maximum ECPC concentrations detected are greater than 10 for mercury and above one for arsenic, copper, and lead. Using the mean concentrations to calculate HQs also indicates low risk with arsenic. Actual risk to receptors within the water body may be lower than that implied by using the SSV in the screening assessment. At Subzone C-1, specific impacts to receptors from water and sediment concentrations would be difficult to determine.



## 9.0 CORRECTIVE MEASURES

According to Permit Condition IV.E. Corrective Action Plan, SCDHEC will review the final RFI report and notify NAVBASE of the need for further investigations, corrective actions, a corrective action study, or plans to meet the requirements of R.61-79.264.101, Corrective Action for SWMUs. This section has been prepared based on SCDHEC's comment that "the RFI report should discuss whether the extent of contamination has been defined, and proposed recommended actions for the SWMUs and AOCs, such as collection of additional samples, proceed into a Corrective Measures Study, or No Further Investigation, whichever is appropriate." EPA and SCDHEC recognizes risk in the  $10^4$  to  $10^6$  as an acceptable risk range. Risk greater than  $10^4$  will require a CMS or if there is an excess risk to ecological resources. The following discussions address the overall approach for looking at corrective measures (CMs), list potential remedies, and outline the steps to be conducted during a CMS. The site-specific conclusions regarding which sites will require CMs are discussed in Section 10, Site-Specific Evaluations.

### 9.1 Introduction

Any CMS at NAVBASE will be conducted according to standard methods presented in the USEPA guidance document, *RCRA Corrective Action Plan* (USEPA, 1994). The standard methodology will be presented in the CMS Work Plan, and will facilitate collecting necessary data, evaluating potential alternatives, and developing a final remedial alternative by establishing a set procedure for evaluation and assessment.

To establish this procedure, the CMS Work Plan will outline the CMS report, discussing basic elements. The overall structure of the plan will be explained to illustrate the decision-making process. Briefly, the report outline is:

<b>Report Outline</b>	1
A. Introduction/Purpose	2
B. Description of Current Conditions	3
C. Corrective Action Objectives	4
D. Identification, Screening, and Development of Corrective Measure Alternatives	5
E. Evaluation of a Final Corrective Measure Alternative	6
F. Recommendation by a Permittee/Respondent for a Final Corrective Measure Alternative	7
G. Public Involvement Plan	8

Each required element will be discussed in detail in the CMS Work Plan. The discussion will achieve the following: 9 10

- Identify minimum requirements for CMS reports in each area. 11
- Define the base pool of technologies to be evaluated for each medium. 12
- Define the evaluation process. 13
- Identify selection criteria for the final corrective measure alternative. 14

Issues to be discussed under each element are identified below: 15

- An activity-specific description of the overall purpose of the CMS for NAVBASE. 16

*SWMUs and AOCs at NAVBASE will be discussed in the CMS Work Plan on a zone-wide basis. Activities, contaminants, and issues specific to each zone will be discussed. The CMS Work Plan will identify: specific sites to be addressed in the CMS, any focused approach (such as naming a primary technology in lieu of the full screening), and the subsequent cleanup goals.* 17 18 19 20 21

- A description of the corrective action objectives for NAVBASE, including how target media cleanup standards, points of compliance, or human health and ecological risk assessments will be established and performed for each site, zone, and activity.

*Cleanup standards will be developed for each site, zone, or activity using the designated exposure scenario (residential, commercial, or industrial) for that area. BRAs (including human health and ecological), conducted in conjunction with the RFI for each zone, will be used to identify areas with unacceptable risk/hazard as per the designated exposure scenario. During the CMS, areas with unacceptable risk will be evaluated according to media, primary contaminants contributing to risk, and the potential for groundwater contamination.*

- Identification, screening, and development of corrective measures alternatives.

*Tables similar to those presented in the NAVBASE RFI work plans will be used in the CMS Work Plan to present the pool of technologies initially evaluated in the CMS. These tables represent a range of technologies with different applications; each technology must be screened and evaluated before it is discarded from further consideration. The tables, therefore, preclude any bias toward a particular technology through full-scale screening techniques.*

*Technologies will be screened using site- and waste-specific characteristics. The CMS Work Plan will identify factors to be considered, including type of media, depth of contamination, areal extent of contamination, number and type of contaminants, remedial goals, excess risk to ecological receptors, future land use scenarios, and adjacent remedial activities. In addition, the CMS Work Plan will present the requirements for implementing Corrective Action Management Units (CAMUs).*

*Once technologies have been screened, they will be assembled into corrective action alternatives. These alternatives will be evaluated according to criteria discussed below.*

- A description of the general approach to investigating and evaluating potential corrective action measures.

*Corrective measures alternatives will be evaluated using four primary and five secondary criteria, listed below:*

***Primary***

1. *Protect human health and the environment*
2. *Attain media cleanup standards set by the implementing agency*
3. *Control the source of releases so as to reduce or eliminate, to the extent practicable, further releases that may pose a threat to human health and the environment*
4. *Comply with any applicable standards for management of wastes*

***Secondary***

1. *Long-term reliability and effectiveness*
2. *Reduction in the toxicity, mobility, or volume of waste.*
3. *Short-term effectiveness*
4. *Implementability*
5. *Cost*

*Alternatives will be discussed and compared according to these criteria, which are used to gauge their relative effectiveness and implementability.*

- A detailed description of how pilot, laboratory, and/or bench-scale studies will be selected, performed, evaluated, reported, and transferred to full scale.

*Treatability studies will be implemented when more involved treatment units are being considered. For example, air stripping technologies usually do not require treatability studies to determine optimal process for treating groundwater. However, ultraviolet (UV)/oxidation, an innovative technology, may require extensive treatability testing to determine oxidant dosages and retention times.*

*The base structure and objectives of a treatability study will be discussed. Objectives may include: dosages, percent reduction in contaminant(s), treatment cost per unit volume, and implementation constraints. Study results will be used to assess the alternatives presented in the CMS and determine the optimal remedial approach for each site, zone, or activity.*

- A description of how statement of basis/response to comments or permit modifications are to be processed.

*Statement of basis/response to comments will be handled through NAVBASE and Southern Division, Naval Facilities Engineering Command (SOUTHDIV). The Comprehensive Long-Term Environmental Action Navy (CLEAN) contractor, EnSafe, will assist the Navy in preparing a statement of basis/response to comments. Permit modifications will be managed through NAVBASE as the permit holder until the base is closed. Upon closure, SOUTHDIV and NAVBASE's caretaker will manage permit modifications. According to the RCRA permit issued May 4, 1990, Appendix C, Facility Submission Summary, a permit modification is required to prepare and conduct a Corrective Action Study/Plan.*



- A description of the overall project management approach, including levels of authority (i.e., organizational charts), lines of communication, project schedules, budgets, and personnel.

*The overall project management is the responsibility of SOUTHDIV for NAVBASE. The lines of authority, communication, and project schedules have been developed and agreed upon and are provided in the Comprehensive Project Management Plan dated August 30, 1994, and amendments. In general, NAVBASE is responsible for ensuring that conditions of the permit are satisfied with the ultimate responsibility held by the Commander of Charleston Naval Shipyard (CNSY). The budget for conducting a CMS is defined by SOUTHDIV and funds are provided by the U.S. Congress. Personnel to conduct the CMS will be assigned by EnSafe on an as-needed basis for project-specific items. EnSafe will manage the CMS effort through EnSafe's Charleston, South Carolina, office.*

- Qualifications of personnel to direct or perform the work will be described.

*EnSafe will use trained qualified and/or registered geologists and engineers of South Carolina where required.*

## 9.2 Remedy Selection Approach

As agreed in the *Final Comprehensive Project Management Plan* (E/A&H, 1994), remedies will be selected in accordance with statutory and RCRA CMS criteria. Particular attention will be given to the following items when evaluating alternatives:

- Background concentrations, particularly of inorganic compounds
- Land use/risk assessment

- Base-wide treatment facilities 1
- Presumptive remedies 2
- Remedies for petroleum, oils, lubricants, and other contaminants of this type 3

CAMUs and temporary units (TUs) will be used where necessary to facilitate storage and treatment during remediation activities. 4  
5

### **9.3 Proposed Remedy** 6

Before selecting and implementing CMs for releases, environmental and cost-effectiveness goals must be established. Typically, the environmental goal is to reduce exposure via direct contact with air, groundwater, and surface water pathways to some level of acceptability. The cost-effectiveness goal is usually to achieve the environmental goals using the least costly alternative that is both technically feasible and reliable. 7  
8  
9  
10  
11

### **9.4 Development of Target Media Cleanup Goals** 12

Cleanup goals will be developed for each site at NAVBASE where human health and/or ecological risk exceeds acceptable levels as specified in the Part B permit. Sites requiring further remediation will undergo CMS. During the CMS, alternatives will be developed for future residential and/or future worker scenarios. Two sets of alternatives may be presented for each site; they may differ due to the media cleanup standards required under residential versus site worker scenarios. 13  
14  
15  
16  
17

The USEPA guidance document, *RCRA Corrective Action Plan* (USEPA, 1994) outlines issues to be considered in developing cleanup goals for groundwater, soil, surface water, sediment, and air. These recommendations are outlined below. 18  
19  
20

#### **9.4.1 Groundwater Cleanup Goals** 21

The CMS will provide information to support the development of groundwater cleanup goals for all Appendix IX constituents found in groundwater during the facility investigation. The following information may be required: 22  
23  
24

- For any constituents for which an MCL has been promulgated under the Safe Drinking Water Act, the MCL value; 1  
2
- Background concentration of the constituent in groundwater; and 3
- An alternate standard (e.g., an alternative concentration limit for a regulated unit) to be approved by the implementing agency. 4  
5

Additional factors to be considered while developing cleanup goals include the classification and primary use of the contaminated groundwater unit, proposed future uses for groundwater, proximity to surface water, etc. 6  
7  
8

#### 9.4.2 Soil Cleanup Goals 9 10

The CMS will provide information to support the development of soil cleanup goals. The following information may be required: 11  
12

- The volume, physical, and chemical characteristics of the wastes in the unit; 13
- The effectiveness and reliability of containing, confining, and collecting systems and structures in preventing contaminant migration; 14  
15
- The hydrologic characteristics of the unit and the surrounding area, including the topography of the surrounding land; 16  
17
- Regional precipitation patterns; 18

- The existing quality of surface soil, including other sources of contamination and their cumulative impacts on surface soil; 1  
2
- The potential for contaminant migration and impact to the underlying groundwater; 3
- The land use patterns in the region; 4
- The potential for health risks caused by human exposure to waste constituents; and 5
- The potential for damage to wildlife, food chains, and vegetation caused by exposure to waste constituents. 6  
7
- The potential for damage to domestic animals, crops, and physical structures caused by exposure to waste constituents. 8  
9

Additional information that may be considered includes background soil concentrations, regulatory guidance (e.g., UST guidance documents). 10  
11

#### **9.4.3 Surface Water and Sediment Cleanup Goals** 12

The CMS will provide information to support the development of surface water and sediment cleanup goals. The following information may be required: 13  
14

- The volume and physical and chemical characteristics of waste in the unit; 15
- The effectiveness and reliability of containing, confining, and collecting systems and structures in preventing contaminant migration; 16  
17

- The hydrologic characteristics of the unit and the surrounding area, including the topography of surrounding land; 1  
2
- Regional precipitation patterns; 3
- The quantity, quality, and direction of groundwater flow; 4
- The proximity of the unit to surface water; 5
- The current and potential uses of nearby surface water and any established water quality standards; 6  
7
- The existing quality of surface water, including other sources of contamination and their cumulative impacts on surface water; 8  
9
- The potential for damage to wildlife, food chains, and vegetation caused by exposure to waste constituents; 10  
11
- The potential for damage to domestic animals, crops, and physical structures caused by exposure to waste constituents; 12  
13
- The land use patterns in the region; and 14
- The potential for health risks caused by human exposure to waste constituents. 15

Additional data which may be considered include the presence of endangered, threatened, or ecologically sensitive species, National Oceanic and Atmospheric Association sediment values, etc. 16  
17  
18



#### **9.4.4 Air Cleanup Goals**

The CMS will provide information to support the development of air cleanup goals. The following information may be required:

- The volume and physical and chemical characteristics of the waste in the unit, including its potential for the emission and dispersal of gases, aerosols, and particulates;
- The effectiveness and reliability of systems and structures to reduce or prevent emissions of hazardous constituents to the air;
- The operating characteristics of the unit;
- The atmospheric, meteorological, and topographic characteristics of the unit and the surrounding areas;
- The existing quality of the air, including other sources of contamination and their cumulative impact on that medium;
- The potential for health risks caused by human exposure to waste constituents; and
- The potential for damage to wildlife, food chains, and vegetation caused by exposure to waste constituents.
- The potential for damage to domestic animals, crops, and physical structures caused by exposure to waste constituents.

1 Other factors which may be considered include National Ambient Air Quality Standards, state and  
2 local air quality regulations, etc.

## 3 **9.5 Identification, Screening, and Development of Corrective Measures Technologies**

4 The initial step in assembling corrective measures alternatives is to identify, screen, and develop  
5 corrective measure technologies that apply to the site. Technologies are typically screened using  
6 waste-, media-, and site-specific characteristics. This section addresses the range or technologies  
7 that may be assessed for each site, the screening process, and screening criteria.

### 8 **9.5.1 Identification of Corrective Measure Technologies**

9 Each site will be assessed using the cleanup standard methodology described in Section 9.2. An  
10 initial list of impacted media and contaminants of concern have been identified in the RFI. The  
11 site-specific BRAs in Section 10 will identify soil and groundwater as the contaminated media.  
12 For each site, the major contaminants present have been grouped into one or more of the following  
13 categories:

- 14 • Chlorinated volatiles
- 15 • Nonchlorinated volatiles
- 16 • Chlorinated semivolatiles
- 17 • Nonchlorinated semivolatiles
- 18 • Pesticides/herbicides
- 19 • PCBs
- 20 • Dioxins
- 21 • Inorganic compounds (includes metals)
- 22 • Petroleum hydrocarbons

1 Remedial technologies are described in Section 9.5.2 of this document. Table 9.1 lists  
2 non-treatment options for soil, groundwater/leachate, sediment, surface water, and air. These  
3 options include removal containment, and disposal. Table 9.2 lists types of compounds and the  
4 recommended types of treatment for each medium. These tables supply general waste management  
5 options for various situations.

6 It should be noted that some sites may contain a combination of contaminants (i.e., inorganics,  
7 pesticides, and petroleum hydrocarbons). As a result, multiple technology types may be required  
8 to remove these contaminants. However, some sites will only contain one type of contaminant.

9 The following example presents a common situation where more than one type of contaminant  
10 exists at a site. The site contains volatile and semivolatile compounds that have been identified  
11 as slightly exceeding risk-based remedial goals. A containment alternative in this situation may  
12 include fencing to restrict unauthorized access, aerating the contaminated area, adding fertilizer  
13 and enriched soil, seeding to maintain a vegetative cover to control runoff, and monitoring. This  
14 containment approach seeks to minimize health risks through land management and natural  
15 attenuation.

16 As discussed in previous sections, because each site may be evaluated under both residential and  
17 site worker scenarios, COCs may vary between scenarios. Two lists of applicable technologies  
18 may be developed for each site, one for each scenario.

**Table 9.1**  
**Removal/Containment/Disposal Options**

Action	Soil	Groundwater/ Leachate	Sediment	Surface Water	Air
Removal	Excavation	Groundwater extraction Leachate collection	Dredging	Diversion Pumping	N/A
Containment	Institutional controls Capping Storm water controls Long-term monitoring Intrinsic (natural) bioremediation/attenuation	Slurry wall Gradient controls Long-term monitoring Intrinsic (natural) bioremediation/attenuation	Berms/diversion Storm water controls	Diversion	N/A
Disposal	Landfill	POTW NPDES Discharge Land application	Landfill	POTW NPDES Discharge	Discharge via air permit

**Notes:**

POTW = Publicly Owned Treatment Works  
 NPDES = National Pollutant Discharge Elimination System  
 N/A = Not Applicable

Table 9.2  
 Treatment Technology Options

Contaminant Type	Soil	Groundwater/ Leachate	Sediment	Air
Chlorinated volatiles	Soil washing	Chemical Oxidation	Same as soil	Oxidation
	Incineration	Bioremediation		
	Thermal desorption	Adsorption		
	Bioremediation	Air stripping UV/Ozone Oxidation		
Nonchlorinated volatiles	Soil washing	Oxidation	Same as soil	Adsorption Oxidation
	Incineration	Bioremediation		
	Thermal desorption	Adsorption		
	Soil Vapor Extraction	Air stripping		
	Bioremediation			
	Steam extraction			
Chlorinated semivolatiles	Soil washing	Oxidation	Same as soil	Adsorption Oxidation
	Bioremediation	Bioremediation		
	Incineration	Air stripping		
	Thermal desorption Solidification/stabilization			
Nonchlorinated semivolatiles	Soil washing	Oxidation	Same as soil	Oxidation Adsorption
	Incineration	Bioremediation		
	Thermal desorption	Sorption		
	Bioremediation Solidification/stabilization			



Table 9.2  
 Treatment Technology Options

Contaminant Type	Soil	Groundwater/ Leachate	Sediment	Air
Pesticides/ Herbicides	Solidification/stabilization Soil washing Bioremediation Incineration Thermal desorption	Oxidation Bioremediation Sorption	Same as soil	Oxidation
PCBs	Solidification/stabilization Soil washing Dehalogenation Incineration Thermal desorption	Oxidation Dehalogenation Incineration Solidification	Solvent extraction Dehalogenation Solidification/stabilization	Oxidation
Dioxins	Incineration Solidification/stabilization	Oxidation		Oxidation
Inorganics	Solidification/stabilization Soil washing	Chemical Precipitation Adsorption Sedimentation Filtration	Same as soil	Filtration Scrubbers Adsorption

### 9.5.2 Description of Pre-screened Technologies

The following paragraphs describe technologies that appear to be the most feasible for the initial CMS. These technologies are divided into four categories: in-situ soil, ex-situ soil, in-situ groundwater, and ex-situ groundwater.

#### *In-Situ Soil*

##### **Bioremediation**

This technology uses microorganisms to biologically oxidize contaminants into harmless chemicals such as carbon dioxide and water. The organisms can be naturally occurring or they can be added to the soil. In many circumstances, nutrients can be supplemented to enhance this process. Nitrate and phosphate are often the limiting nutrients at a site. However, having insufficient electron acceptors is the greatest variable limiting bioremediation. The most common electron acceptor is oxygen for aerobic biodegradation. For these sites, it is likely that bioremediation via natural attenuation is a good candidate for some of the compounds. Typically nonchlorinated VOCs and SVOCs are good candidates for this technology.

##### **Solidification/Stabilization**

This technology consists of mixing reagents with soil to prevent contaminants from leaching to the groundwater below. This technology immobilizes contaminants, preventing migration. However, this technology does not remove the contaminant.

#### *Ex-Situ Treatment of Soils*

All ex-situ soil treatments require excavation to another location or at least bringing the material to the surface. Typically heavy equipment is used to move the soil. If contaminated soil is limited

in volume and considered nonhazardous, it may be feasible to dispose of it in a landfill. If sites have a limited area of contaminated soil, it may be feasible to remove the soil with heavy equipment and treat it ex-situ, or if nonhazardous, it could be disposed of in the SWMU 9 landfill.

### **Soil Washing**

Soil washing physically separates soil particles by size, then treats the smaller grains with solutions that desorb the contaminants. The resulting solution containing contaminants is then treated by another technology. In general, small soil particles such as clay and silt have a higher TOC content, which tends to absorb hydrophobic compounds such as chlorinated contaminants. Essentially the technology compacts contaminated soil, then washes it with a solvent to remove the contaminants.

### **Thermal Desorption**

Thermal desorption technologies are performed at high or low temperatures, depending on the contaminant. Both of these technologies are used in combination with incineration or some other type of offgas treatment. Soil is excavated and put in the treatment systems for both high- and low-temperature desorption to separate the contaminants from the soil, not to destroy the chemicals. The volatilized contaminants enter an air stream and travel to some type of gas treatment for the contaminant destruction. Low-temperature (200°F to 600°F) thermal desorption (LTDD) is only applicable for VOCs while high-temperature (600°F to 1000 °F) thermal desorption (HTDD) is applicable for SVOCs, PAHs, PCBs, and pesticides.

### **Thermal Destruction/Incineration**

This technology is used in conjunction with ex-situ soil technologies. Typically the contaminant is removed from the soil matrix and transferred to an air stream. The air stream is treated with the thermal destruction on a catalyst or burned in an incinerator or a combination of the two. High

temperatures (1,800°F to 2,000°F) are required to destroy organics such as PCBs, dioxins, furans, pesticides, and others.

### **Solidification/Stabilization**

This technology is similar to the in-situ methods; however, the soil is first excavated before being mixed with the chemical reagents or concrete.

### ***In-Situ Groundwater Treatment***

#### **Bioremediation**

Bioremediating contaminants in groundwater involves adding nutrients (phosphate, nitrate, etc.) and an electron acceptor (i.e., oxygen, nitrate, etc.) to the groundwater via injection wells. The most typical electron acceptor addition comes from either oxygen via air sparging, and/or nitrate with the addition of other nutrients.

#### **Intrinsic Remediation**

This technology, also called natural attenuation, simply allows naturally occurring bioremediation, oxidation, hydrolysis, dispersion, and advection to occur unassisted. No nutrients or electron acceptors are added to the site. The site may be monitored to observe the contaminant reduction. Many case studies have demonstrated this technology on TPH analysis.

#### ***Ex-Situ Treatment of Groundwater***

Any ex-situ treatment of groundwater requires a system of extraction wells and pumps to deliver the groundwater to the treatment location.

## **Chemical Precipitation**

The solubility of many metals is a function of pH. As a result, chemical agents can be added to change the pH of the water, that results in the metals becoming insoluble. In other cases, a chemical can be added to chelate the metal and precipitate it out of the solution. Either way, the contaminants can then be removed by filtering.

## **Air Stripping**

Groundwater can be extracted from the subsurface and pumped to a nearby publicly owned treatment works (POTW). While the contaminated groundwater is in the aeration basin of the water treatment plant, the volatile compounds (compounds with a high Henry's Law Constant) will mass transfer from the water to the air. Steam can also be used to heat the groundwater, causing organics to volatilize. These air vapors can be treated with an appropriate technology or can be permitted as an air emission source.

## **Chemical Oxidation/UV-Ozone**

Ozone is one of the strongest chemical oxidizers. Almost any organic compound can be oxidized. Ozone can be generated with UV light sources. Water can pass through a flowstream surrounded by UV lights. Oxygen in the water is converted to ozone and the organics are oxidized into harmless by-products. Compounds that typically are recalcitrant to biological oxidation, such as chlorinated organics, can easily be oxidized with ozone. Good light transmission is essential; therefore, very turbid water is not a good candidate for UV ozonation.

## **Activated Sludge**

Activated sludge treatment of wastes occurs in a wastewater treatment plant. The activated sludge process uses microorganisms to convert organic wastes to inorganic wastes and/or bacterial cell mass, carbon dioxide, and water.



### **9.5.3 Screening Criteria**

When more than one technology applies to a specific site, it is necessary to evaluate their limitations to show why certain CMS technologies may prove infeasible to implement waste- and site-specific conditions. Therefore, for each technology, the following criteria will be discussed:

- Site Characteristics
- Waste Characteristics
- Technology Limitations

#### **Site Characteristics**

Site characteristics define the site and any constraints that may impact selecting and implementing remedial technologies. Characteristics to be considered include primarily the current and future use of the site or SWMU. Other characteristics include the contaminated media, areal distribution of contamination, and depth to/of contamination. Current migration pathways and the potential for intrinsic remediation will also be considered. Each site may have one or two technology lists that will be evaluated for residential and BRAC-specified future uses.

#### **Waste Characteristics**

Waste characteristics define the nature of contamination. The primary waste characteristic to be considered is the general type of contamination — volatiles, semivolatiles, pesticides/herbicides, PCBs, dioxins, inorganic compounds, and TPH analysis. Also critical is the presence of halogenated compounds, such as chlorinated benzenes or trichloroethylene.

Where multiple types of contamination are present (such as PCBs and dioxins, or pesticides and volatiles), certain technologies may be eliminated from consideration due to the inability to

effectively treat the wastes. For example, soil vapor extraction (SVE) typically is not used on pesticide sites, although it is very effective for most volatile compounds. If both contaminants must be treated concurrently, SVE would be eliminated from further evaluation. Where appropriate, contaminant concentrations will be considered to screen remedial technologies.

### **Technology Limitations**

Technology limitations are used to assess the implementation feasibility of a particular technology. These limitations may include technical restrictions on application, including the presence of a shallow water table, depth to bedrock, etc. Additional limitations include minimum or maximum process volumes, such as technologies that are cost-effective only when contaminated soil volume exceeds 1,000 cubic yards. Other limitation to be assessed include effectiveness in meeting treatment goals and remedial time frame. Technologies meeting this screening criterion may differ from residential to BRAC-specified use scenarios due to the differences in cleanup goals for each scenario.

## **9.6 Identification of Corrective Measure Alternatives**

Once specific remedial technologies are identified for the site; they will be assembled into specific alternatives that may meet the corrective action objectives for all media. Each alternative may consist of an individual technology or a combination of technologies used in sequence (i.e., treatment train). Depending upon site-specific situations, different alternatives may be considered for separate areas of the facility.

Less complex sites may be relatively straightforward and may only require evaluating one or two alternatives. Because the NAVBASE CMS will evaluate both residential and BRAC-specified future uses, two sets of alternatives may be developed for each site.

## **9.7 Evaluation of Corrective Measure Alternatives**

Each alternative proposed (including single proposed alternatives) will be evaluated according to five standards reflecting the major technical components of remedies, including cleanup of releases, source control, and management of wastes that are generated by remedial activities. The specific standards are provided below.

- Protect human health and the environment.
- Attain media cleanup standards set by the implementing agency.
- Control the source of releases so as to reduce or eliminate, to the extent practical, further releases that may threaten human health and/or the environment.
- Comply with any applicable standards for managing wastes.
- Consider other factors.

These standards are detailed in the following sections.

### **9.7.1 Protect Human Health and the Environment**

Corrective action remedies must be protective of human health and the environment. The degree of protection afforded by each alternative will be discussed in this section.

Remedies may also include those measures that are needed to be protective, but are not directly related to media cleanup, source control, or waste management. For example, access controls and deed restrictions may be implemented to prevent contact with contaminated media while intrinsic remediation or attenuation processes are monitored or augmented. This section will discuss any short-term remedies that may be implemented to meet this standard.

#### **9.7.2 Attain Media Cleanup Standards Set by the Implementing Agency**

Each alternative will be evaluated as to whether the potential remedy will achieve the remedial objective(s). This evaluation will estimate the time frame needed for each alternative to attain these standards. The selected remedy will be required to attain media cleanup standards set by the implementing agency, that may be derived from current state, federal, or other regulations or standards. The media cleanup standard will often play a large part in determining the extent of and technical approaches to the remedy. In some cases, the practical capabilities of remedial technologies (or other technical aspects of the remedy) may influence, to some degree, the cleanup standards that are established.

#### **9.7.3 Control the Sources of Releases**

As part of the CMS report, source control measures will be evaluated to determine if they are necessary to control or eliminate further releases that may threaten human health or the environment. If a source control measure is proposed, it will include a discussion on how well the method is expected to work, given site conditions, and the known reliability of the selected technology.

Source control measures will be considered when it is necessary to stop further environmental degradation by controlling or eliminating further releases that may threaten human health or the environment. In some cases efforts to clean up releases without source control measures, may be

ineffective or (at best) will essentially involve a perpetual remedial effort. In these cases, an effective source control program may be essential to ensure the long-term effectiveness and protectiveness of the corrective action program. Source control measures may include all protective remedies to control the source. Such remedies may include partial waste removal, capping, slurry walls, in-situ treatment and/or stabilization, and consolidation.

#### **9.7.4 Comply with Any Applicable Standards for Management of Wastes**

Each alternative will discuss how the specific waste management activities will comply with all applicable state or federal regulations, such as closure requirements, land disposal restrictions, etc.

#### **9.7.5 Other Factors**

Five general factors will be considered in selecting/approving a remedy that meets the standards listed above. These factors combine technical measures and management controls to address the environmental problems at the site. The five general decision factors include:

- Long-term reliability and effectiveness
- Reduction in the toxicity, mobility, or volume of wastes
- Short-term effectiveness
- Implementability
- Cost



### **Long-Term Reliability and Effectiveness**

The CMS will evaluate whether the technology or a combination of technologies has been used effectively under similar site conditions, whether failure of any one technology in the alternative would have an immediate impact on receptors, and whether the alternative would have the flexibility to deal with uncontrollable changes onsite.

This criterion will assess the proposed useful life of the overall alternative and its component technologies. Useful life is defined as the length of time the level of effectiveness can be maintained. Typically, most corrective measure technologies deteriorate with time. Deterioration can often be slowed through proper system operation and maintenance, but the technology may eventually require replacement to maintain effectiveness. The CMS will consider these issues.

### **Reduction in the Toxicity, Mobility, or Volume of Wastes**

This criterion will be used to assess the degree that each alternative reduces the toxicity, mobility, or volume of wastes. In general, preferred remedies employ treatment and are capable of eliminating (or substantially reducing) the potential for contaminated media to cause future environmental releases or other risks to human health and the environment. Estimates of how much the corrective measure alternatives will reduce the waste toxicity, mobility, or volume may help in assessing this criterion.

In some situations, reducing toxicity, mobility, or volume may not be practical or even desirable. For example, large municipal-type landfills or unexploded munitions may be extremely dangerous to handle. In these situations, the short-term risks of treatment outweigh the potential long-term benefits.

### **Short-Term Effectiveness**

The short-term effectiveness of each alternative will be assessed, including: the potential for fire, explosion, and exposure to hazardous substances; as well as threats associated with treatment, excavation, transportation, and redisposal or containment of waste material. This criterion is important in densely populated areas and where waste characteristics are such that risks to workers or to the environment are high and special protective measures are needed.

### **Implementability**

Each alternative will be evaluated to assess any potential impacts on the time required to implement a given remedy. Information to consider for implementability includes:

- The administrative activities needed to implement the corrective measure alternative (e.g., permits, rights-of-way, offsite approvals) and the length of time these activities will take.
- The constructability, time for implementation, and time for beneficial results.
- The availability of adequate offsite treatment, storage capacity, disposal services, needed technical services, and materials.
- The availability of prospective technologies for each corrective measure alternative.

### **Cost**

The CMS will consider the relative cost for each remedy. This criterion is especially useful when several technologies offer the same degree of protection to human health and the environment but vary dramatically in cost. Cost estimates will include: engineering, site preparation, construction,

1 materials, labor, sampling/analysis, waste management/disposal, permitting, health and safety  
2 measures, training, operations and maintenance, etc.

## 3 9.8 Ranking the Corrective Measures Alternatives

4 Once corrective measures have been discussed for each site using applicable scenarios (residential  
5 and/or BRAC-specified future use), alternatives under each will be ranked in order of desirability.  
6 The ranking system has been developed with input from the Restoration Advisory Board, to  
7 determine the importance of each corrective measure criterion. The system is included in the  
8 *Comprehensive CMS Work Plan* (E/A&H, 1997). Table 9.3 shows the format of the ranking  
9 system.

10 The example presented in Table 9.3 considers a hypothetical site in which soil is contaminated  
11 with relatively high (10 to 1,000 ppm) PAH concentrations. Three alternatives were developed:  
12 excavation and disposal in a permitted landfill, excavation and thermal treatment, and capping in-  
13 situ. The purpose of this example is to show the format and the nature of comparisons that will  
14 be made in the CMS.

15 Once the weighing factors are selected, the rankings are set by multiplying the criteria values by  
16 the weighing factor. The weighted criteria values are then summed. Alternatives are ranked in  
17 order, with the highest total being most preferable, and the lowest total being the least preferable.

Table 9.3  
Comparison and Ranking of Alternatives

Objective & Criteria	Weighing Factor	Alternative 1			Alternative 2			Alternative 3		
		Description	Meets Criteria	Weighted Criteria Value	Description	Meets Criteria	Weighted Criteria Value	Description	Meets Criteria	Weighted Criteria Value
Protect human health and the environment		Protective of human health and community	3		Protective of human health and community	3		Protective of human health and community	3	
Attain media cleanup standards		Excavates soil above cleanup goals	3		Excavates soil above cleanup goals	3		No	1	
Control the sources of releases		Eliminates source material above cleanup goals	3		Eliminates source material above cleanup goals	3		Controls sources of releases through containment, reduction in leachate	3	
Comply with any applicable standards for management of wastes		Must comply with LDRs, USDOT regulations	3		Must comply with LDRs, air emissions regulations	3		Must comply with RCRA cap requirements, monitoring	3	
<b>Other Factors</b>										
Long-term reliability and effectiveness		Effective over the long term	3		Effective over the long term	3		Effective with regular maintenance activities.	3	
Reduction in toxicity, mobility, and volume		Does not reduce toxicity, mobility, or volume	1		Reduces toxicity, mobility, and volume through treatment	4		Does not reduce toxicity, mobility, or volume	1	

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Table 9.3  
Comparison and Ranking of Alternatives

Objective & Criteria	Weighing Factor	Alternative 1			Alternative 2			Alternative 3		
		Description	Meets Criteria	Weighted Criteria Value	Description	Meets Criteria	Weighted Criteria Value	Description	Meets Criteria	Weighted Criteria Value
Short-term effectiveness		Minimal exposure to site workers during excavation	3		Minimal exposure to site workers during excavation and treatment	3		Minimal exposure to site workers during excavation	4	
Implementability		Easily implemented, common approach to contaminated soil	4		Requires mobile treatment unit mobilization; may be time inefficient	2		Easily implemented, common approach to contaminated soil	3	
Cost		Present worth cost = \$193,000	3		Present worth cost = \$334,000	1		Present worth cost = \$8,000	4	
Totals										

Notes:

Meets criteria ranking values are based on the following scale:

- 4 = Meets and far exceeds criteria/objectives
- 3 = Slightly exceeds criteria/objectives
- 2 = Meets only minimally the criteria/objectives
- 1 = Does not meet criteria/objectives

Weighing Factors will be determined by NAVBASE  
LDRs = Land Disposal Restrictions  
USDOT = U.S. Department of Transportation